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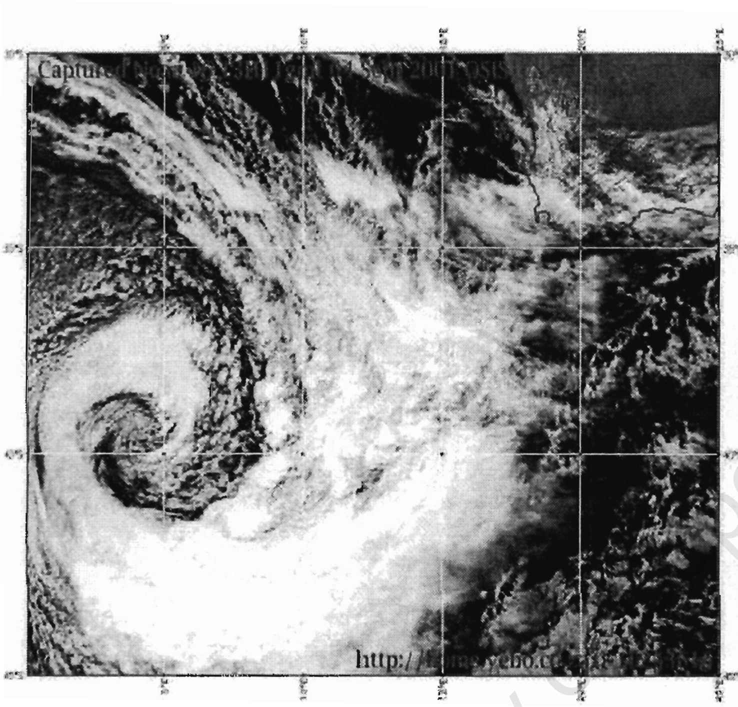

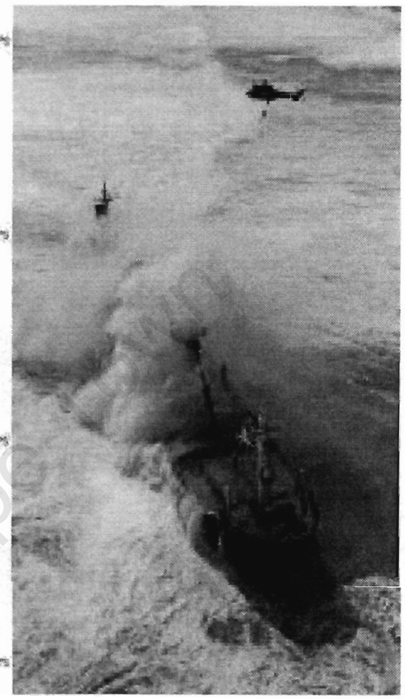

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Dissertation project for:

University of Cape Town

CSIR
ENVIRONMENTEK

Characteristics of extreme wave events and the correlation between atmospheric conditions along the South African coast.

Prepared by Emile van der Borch van Verwolde

Dissertation approved for the degree
Master in applied marine Science
At the Oceanography department, University of Cape Town

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April 2004

Pictures on cover:
Storm Sept. 2001: courtesy of NOAA
Ikan Tanda: courtesy of www.marine-salvage.com

Abstract

Characteristics of extreme wave events along the coast of South Africa were researched through a dataset obtained by CSIR wave recording network at four locations. The locations from west to east are Slangkop, FA-Platform (Agulhas bank), East London and Richards Bay. The longest dataset available was the 25-year dataset at Slangkop measured by accelerometer wave buoys. In the subsequent years the wave recording network along the South African coast was expanded to six locations at present.

A hundred extreme wave events were identified along the South African coast according to the set up criteria. All data of the identified extreme wave events were processed and analysed by looking at the following characteristics:

- Wave characteristics
  - Hmo, Hs, $H_{1/3}$ (significant wave height in m)
  - Hmax (Maximum wave height in m)
  - Tp (Peak period in s)
  - Wave direction (degrees)
- Duration of events (hours)
- Rate of increasing wave height (mhr^{-1} or $mday^{-1}$)

Very pronounced differences exist between locations. Slangkop and FA-Platform have similar event characteristics, but when rounding the south coast towards East London a rapid decrease of wave height is present. Other event characteristics follow similar patterns. The highest Hmax recorded around South Africa is 17.9 m and was recorded on the Agulhas Bank.

Specific atmospheric conditions are responsible for the extreme wave events along the South African coast and were analysed for every identified extreme wave event. Cold fronts are responsible for the majority of extreme wave events followed by "explosive" cyclogenesis and cut-off lows. Tropical cyclones and coastal lows do not count for many extreme wave events, but have to be taken into consideration on the east coast.

There is a reduction in wave height between FA-Platform and East London, which continues to Richards Bay. The weakening or dissipation of weather patterns generating the extreme wave is the principal reason.

Acknowledgements

Firstly I want to acknowledge my supervisor Prof. Geoff Brundrit from the Oceanography department at University of Cape Town who was always there for me if I had questions or when I needed guidance during my dissertation.

Special thanks to my supervisor Mr. Hans Moes from the CSIR who guided this dissertation project. I am very grateful to the CSIR, which provided me with all the wave data, an office and a computer. I was able to make use of all the facilities within the CSIR and it has to be emphasised that it was a great experience to work in an environment like this.

I also want to acknowledge some people from the CSIR who helped me with specific questions or problems. Firstly, Ursula Von St Ange who helped me with the data processing in Excel, secondly Louise Watt, who was so kind to make all the direction versus period plots for this thesis, thirdly Marius Rossouw who gave me specific information and answering some questions, fourthly Steven Pietersen who extracted all the data required from the main database and finally Louise van der Merwe from the intern library at CSIR, who was there when I needed special information regarding this project.

I also want to acknowledge the South African Weather Service that provided all the relevant weather bulletins and thanks to Ian Hunter from the SAWS who helped me out when I had some difficult questions.

Without the help of the librarian at the Oceanography Department Seta Jackson, I would still be searching for some relevant information regarding this project.

I am also very grateful to the help of Prof. Frank Shillington who answered specific questions concerning the mathematical approach of this dissertation.

And finally I want to acknowledge the taught masters fund at the University of Cape Town, who were so kind to fund petrol for the long drives to the CSIR in Stellenbosch.

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Chapter 1: Introduction

For centuries the ocean area off South Africa has been renowned for being a hostile environment. Since 1500 more than 2,700 ships have run aground, sank or vanished due to the storms in the South Atlantic. These storms that mostly occur in the South Atlantic are the main cause of extreme wave events along the coast of South Africa. Almost every year an extreme wave event will take place and offshore industries, coastal developments, shipping and other marine activities are considered to be vulnerable due to this high wave climate.

A major tanker route stretches along the East African coast, from the Middle East to Europe or the United States. Around 5000 tanker voyages per year are reported, carrying 30% of the world's crude oil production. Of these, 1200 voyages per year are by large tanker (>250 000 tonnes) and 4000 are by middle-sized tanker (~60 000 tonnes). 700 million tonnes per year of crude oil is transported through island waters of the Indian Ocean and 350 million tonnes are transported through the Mozambique Channel (ITOPF, 2003).

Very Large Crude Carriers (VLCC) traveling around South Africa represent a constant, yet relatively low threat to the environment, since their route lies well offshore. However as the vessels come closer to the continental shelf, off the south east coast of South Africa, to make use of the fast flowing Agulhas current, traffic tends to increase in density. The most significant cause of accidents is collision and heavy weather (ITOPF, 2003).

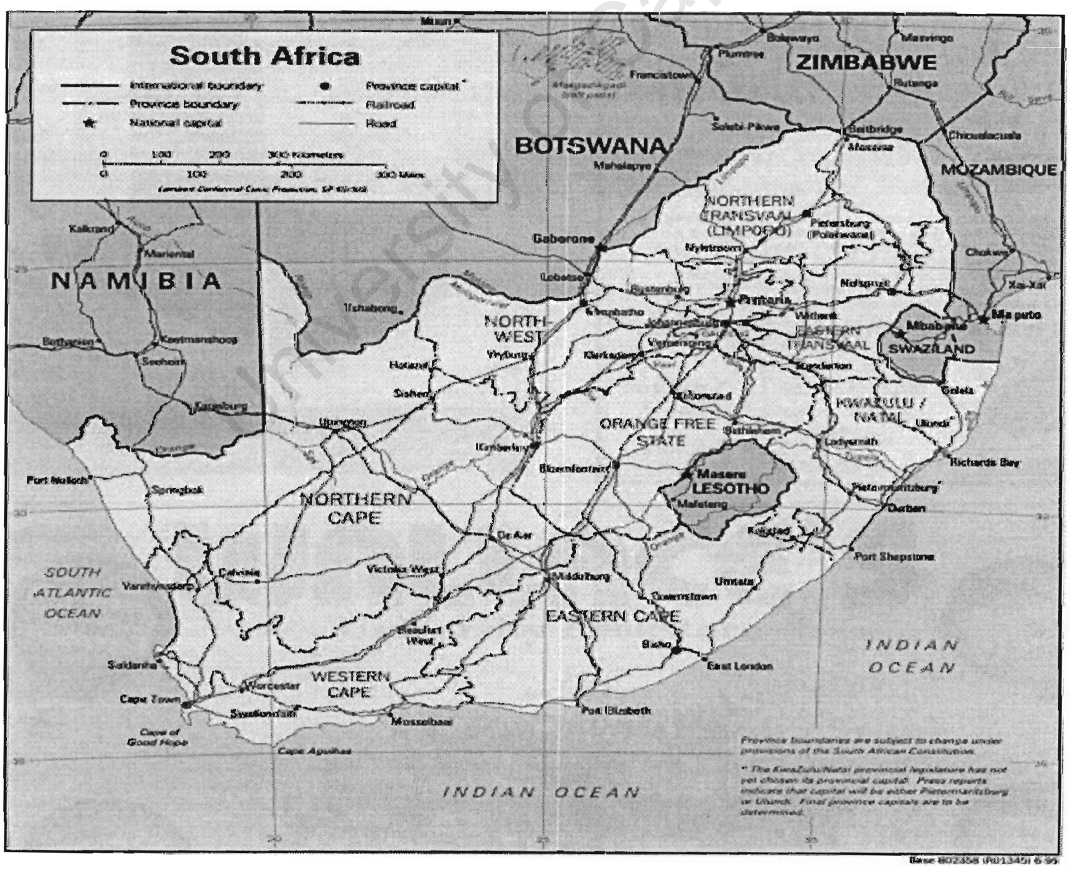


Fig 1: Map of South Africa and its major ports

When vessels pass the South African coastline in territorial waters using the enforced shipping lanes, vessels are required by law to be in good condition. South Africa is also obliged to provide a "safe haven" for vessels sheltering for rough seas and stormy conditions. When vessels are in trouble in territorial waters a judgement call has to be made by port authorities and salvage companies in regard to these requirements.

Almost every year a few vessels are in trouble, get grounded or sink along the South African coast. Therefore it is very important to gain knowledge about the extreme weather and wave events to prevent further loss of vessels and the environment, which will benefit to the national and international economy.

There are 7 major commercial harbours present along the coast of South Africa that import and export products like; petroleum, oil, coals, cargo, containers and other raw materials. The main ports from northwest to northeast are general; Saldanha Bay, Cape Town, Mossel Bay, Port Elizabeth, East London, Durban and Richards Bay (Refer to Fig 1; Map of South Africa and its ports). At the moment South Africa is developing an 8th commercial harbour named Coega near Port Elizabeth.

The National Ports Authority (NPA) operates all major ports in South Africa. NPA needs a wave recording system able to provide real-time wave information to Port Control. This task is undertaken by its technology partner CSIR.

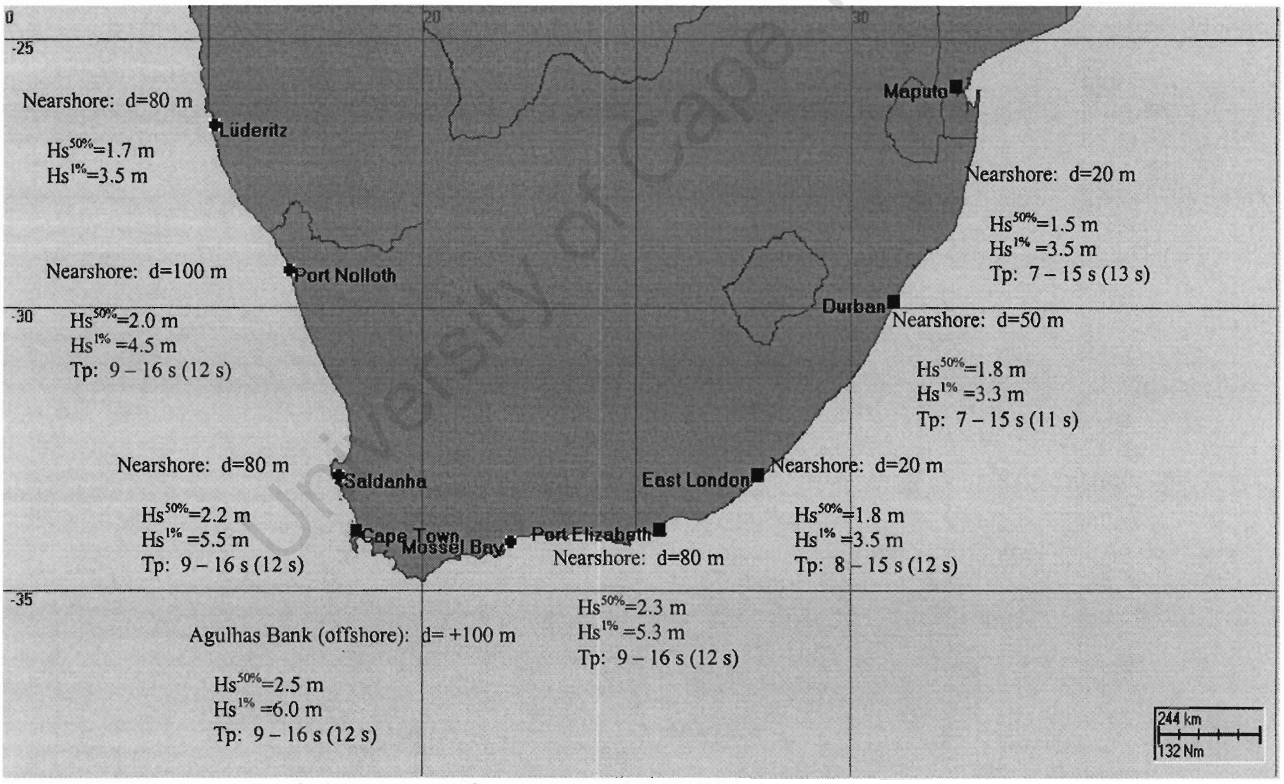


Fig 2: Summaries of the wave climate round South Africa, with the median wave height, wave height exceeded for 1% of the time and the range of peak periods (van der Westhuyzen, 2002)

Summarised wave heights and Peak Periods as can been seen in Fig 2, gives a good impression of the general wave climate of South Africa. The wave climate is considered as an high wave climate with 50% of the waves at the south coast exceeding 2.2 m. Extreme wave events as researched for this project are all falling in the 1% exceedance limit.

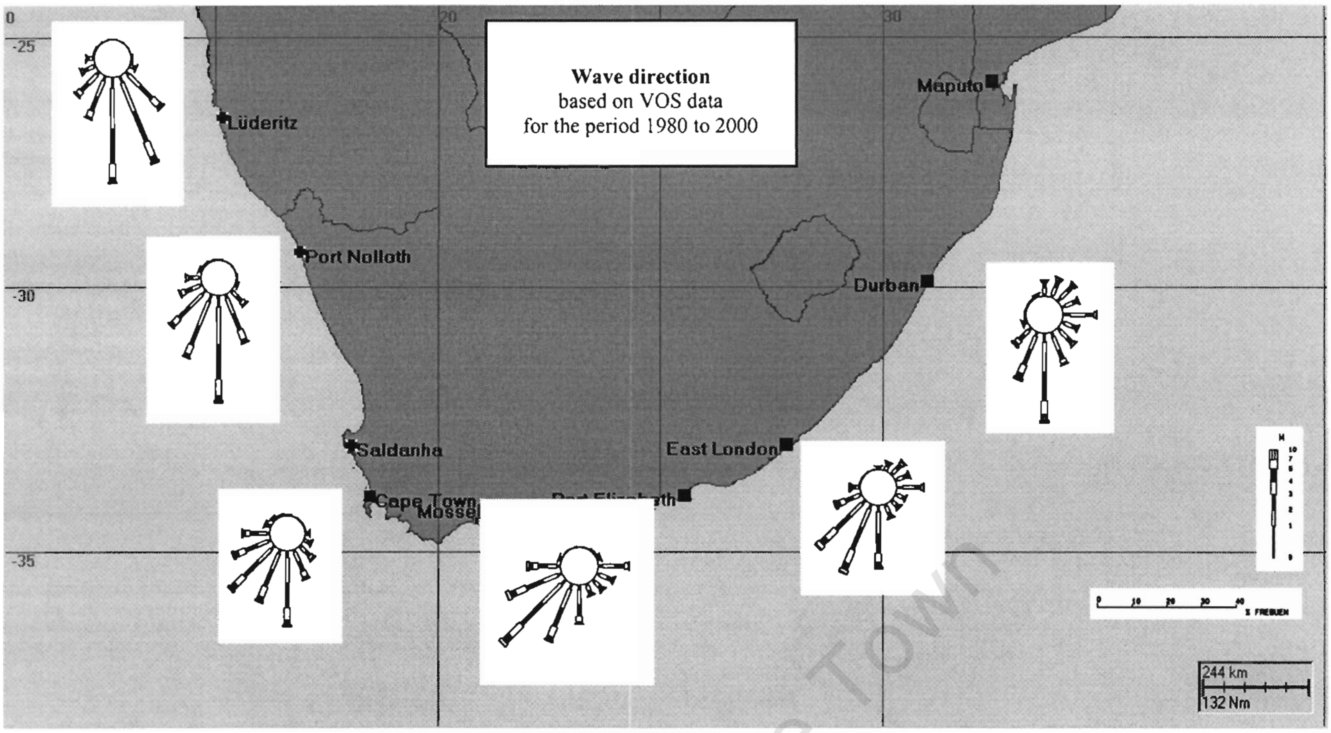


Fig 3: Summaries of the wave directions around the South African coast, as estimated from Voluntary Observing Ship (VOS) data (van der Westhuyzen, 2002).

The general wave directions along the coast of South Africa as seen in Fig 3 are predominantly coming from the south or south west.

At present, observing and forecasting extreme wave events is a routine undertaken by The South African Weather Service (SAWS) and international institutions like the US Navy, NOAA and NCEP. The combination of wave recorders, satellite measurements (GEOSAT since 1986 and TOPEX/POSEIDON since 1992) and meteorological data form a compact network to provide input to wave models like Wavewatch III (Predicting wave characteristics 144 hours in advance for the South Atlantic and Indian oceans.

1.1 Aims of the study

In this study, the development, impacts, and the characteristics of extreme wave events off South Africa are investigated. This leads to the establishment of future expectations of occurrence in respect of extreme wave events (storms) and their prediction. These main objectives will be reached through answering six key questions.

1) What are the characteristics of extreme wave events?

2) Where were these extreme wave events generated?

3) What synoptic weather types are responsible for the extreme wave events?

4) How fast are the weather systems traveling?

5) What is the track of the weather systems?

6) What are the impacts of extreme wave events?

The approach taken is to assemble detail of wave observations in the region to look at correlations and trends of the observations. Then to determine if there are any similarities between events and locations, which will be useful for wave forecasting in future.

1.2 Structure of the thesis

After this introduction chapter a background study to all the relevant subjects for this project is undertaken. It starts with an introduction on ocean gravity waves to get familiar with the physics of waves. After this general introduction of waves, more specific features are discussed such as the South African wave climate and the macro-scale weather patterns of the South African region. In this paragraph, the weather types responsible for extreme wave events are included. Most of the research undertaken is done by analyzing a dataset of wave measurements. Therefore the history of South African wave recording is explained. Finally, in this chapter the impacts of extreme wave events will be discussed.

All the materials used are explained in Chapter 3, includes the location of the buoys that are used for this thesis. Thereafter the methodology to analyse the characteristics of the extreme wave events will be discussed together with errors or missing data in the data set. Finally, the methodology of analyzing the weather types responsible for the extreme wave events will be discussed.

In Chapter 4, the main results will be given and all results that are of secondary importance will be included as appendices.

In the discussion, and conclusions all the outcomes will be evaluated, including the accuracy of methodology used. General conclusions will be given of the characteristics of extreme wave events, the correlation between these events with the atmospheric conditions and the trends. The question 'Is it getting stormier along the South African coast?' will be answered after a description of impacts of extreme wave events along the coast of South Africa. This chapter concludes by indicating further research that can be carried out on this subject.

Chapter 2: Background

2.1 Basics of surface gravity waves:

In this chapter only the basics of ocean gravity waves relevant to this thesis are reviewed. More information of the basics of surface gravity waves can be found in *Waves, Tides and Shallow-Water Processes* by the Open University Course Team (1989).

Generation:
For the formation of ocean gravity waves the drag of the wind on the water particles is the most important factor. The difference in speed between the atmosphere-ocean interface (when wind is blowing) and when there is a frictional stress between these two layers of fluid, deformations of the interface will develop. It was suggested in 1925 by Harold Jeffreys that waves are obtaining energy from the wind virtue of pressure differences caused by the sheltering effect provided by the wave crests.

One might expect that waves will grow till the wave speed is the same as the wind speed, but this assumption is not valid. This is because some of the wind energy is transferred to the ocean surface via a tangential force, which creates a surface current. Some wind energy is dissipated by friction and finally energy is lost from larger waves by white capping.

Not only the wind strength or speed is responsible for the wave size, but also the length of time the wind blows at a certain speed and the unobstructed distance (fetch) over which the wind is blowing plays an important role in wave growth.

Statistical models, like the Wavewatch III model or WAM model, have been designed to assess the probability of the occurrence of waves having specific physical dimensions.

$$(\partial F / \partial t + Cg \cdot \nabla F) = S_{INPUT} + S_{NON\text{-}LINEAR} + S_{WHITE\text{-}CAPPING}$$

This equation is used by wave models for forecasting purposes of an existing wave field in the x, y direction, with the rate of change of energy spectrum F being forced by:

$S_{INPUT} > 0$, gaining energy directly from the wind, particularly at high frequencies

$S_{NON\text{-}LINEAR}$ (Wavewatch III model), wave-wave interaction leading to lower-frequency energy.

$S_{WHITE\text{-}CAPPING} < 0$, loss of energy

Propagation:
Waves propagate from the area of origin and will keep on propagating without any significant loss of energy (wave height). There is some loss in height due to attenuation (e.g. non-linear wave-wave interaction, white capping, air resistance). Characteristics of the waves will only change significantly when they propagate into water with a depth that is ½ the wavelength or through other hindrance or interaction

with landmasses and other waves or winds. Waves that have traveled away from their area of origin is called swell (See Fig 4).

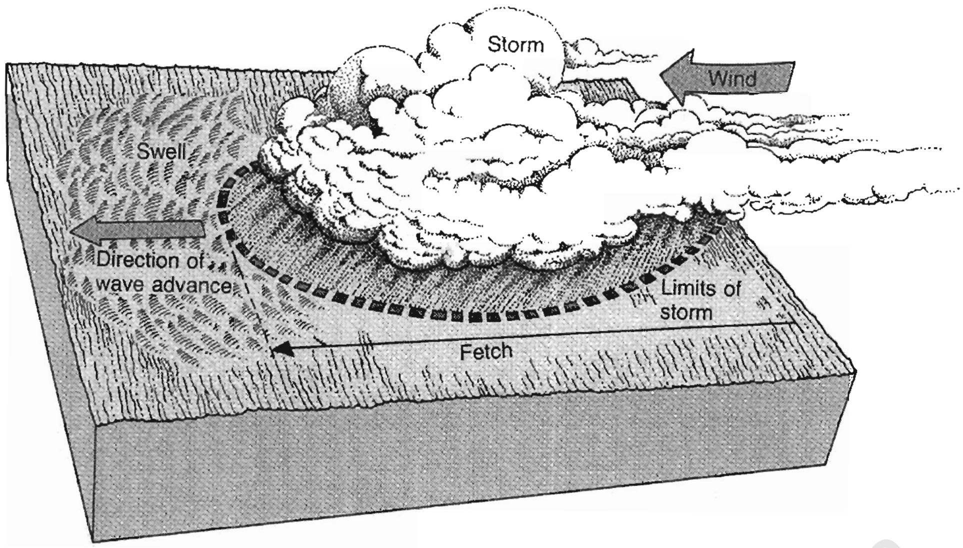


Fig 4: Storm activity and the generation of swell (Thurman, 1997)

The propagation of waves in water is due to the orbital motion of water particles. At the wave crests the waterparticles are moving in the same direction as the propagation of the wave, but in the troughs the particles are moving in a opposite direction (Refer to Fig 5). This orbital motion diameter decreases exponentially with depth until a depth of ½ the wavelength is reached.

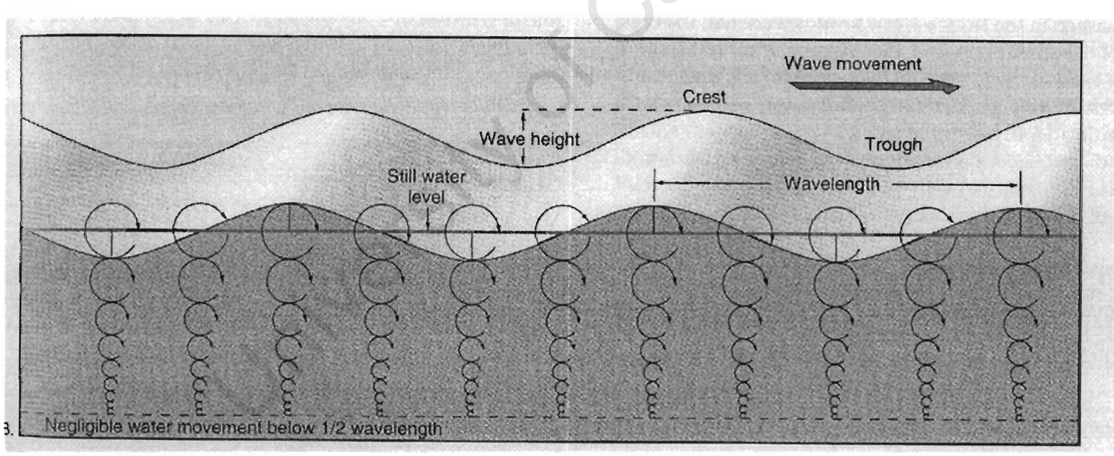


Fig 5: Orbital movement of progressive waves and its components (Thurman, 1997)

Waves that propagate forward in their medium are called progressive waves and have an individual velocity. Both field and laboratory measurements confirm that fast progressive waves have long periods and wavelengths.

When waves travel away from their generation area they begin to separate and sort themselves into groups of waves that have approximately the same period and velocity. This process of wave separation also called dispersion, produces a regular swell. Waves that originated in a storm with the greatest wavelengths and longest periods will travel faster than the waves with smaller wavelengths and shorter periods, and will therefore outrun the smaller period waves and arrive firstly at the coast.

In the ocean, waves tend to form groups, because sets of individual waves interfere with each other. The speed at which a group of waves travel in deep water is about half the wave speed of the individual waves ($Cg_0 = ½ C_0$), which travel through the group of waves. In Fig 6 it can be seen that when the difference in period or wavelength between two sets of waves is relatively small, the two sets will interfere with each other and will result in a single set of waves. Three types of interference exist, constructive wave interference, destructive wave interference and complex wave interference.

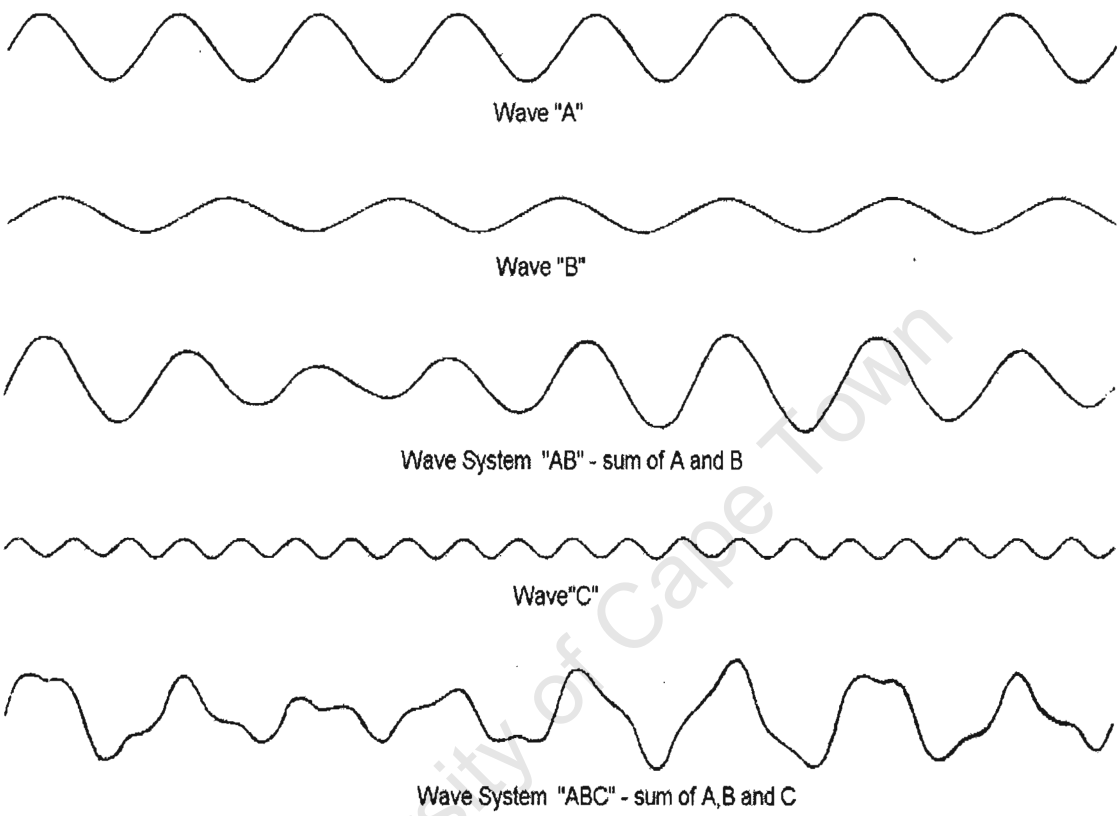


Figure 2 - How simple waves add together to form a random sea.
Note: Wave height/length ratios are greatly exaggerated for clarity.

Fig 6: Wave-wave interaction (Thurman, 1997)

Dissipation of wave energy:
Loss or dissipation of wave energy results in a reduction of wave height. Energy is dissipated in four main ways

1) White-capping
2) Viscous attenuation, only important for the high frequency capillary waves
3) Air resistance
4) Non-linear wave-wave interaction

At one stage, the rate of energy dissipation by the waves is equal to the energy received from the wind and the waves will stay in an equilibrium state. This equilibrium state of the sea is called "a fully developed sea". In "a fully developed sea" the size and characteristics of the waves remain the same.

Wind speeds on the sea however are extremely variable and therefore the waves will be variable in size as well. Therefore, waves are usually referred to as a wave field or a spectrum of wave energies.

Important properties of extreme waves are:

A) Characteristics of extreme waves

- Hmo, Hs, $H_{1/3}$ (significant wave height in m)
- Hmax (Maximum wave height in m)
- Tp (Peak period in s)
- Wave direction (degrees)
- Duration of event (hours)
- Rate of increasing wave height ($mhour^{-1}$)
- Energy spectrum (m^2Hz^{-1})

B) Sea State

Because waves are so variable in size it is necessary to choose a single wave height that characterises a specific sea state. Therefore, the significant wave height ($H_{1/3}$, Hs or Hmo) is defined. The significant wave height is the average height of the 1/3 highest waves or four times the square root of the variance of the wave spectrum.

The Beaufort Scale (Refer to Table 1) is the relationship between the sea state, significant wave height and wind speed. The Beaufort Scale gives a good idea of waves generated within a local weather system.

Table 1: Beaufort wind scale and the State of the Sea

Beaufort Scale	**Descriptive Term**	**Speed (ms^{-1})**	**" " knots**	**State of the sea-surface**	**Wave height (m)**
0	Calm	-	< 1	Like a mirror	0
1	Light air	0.3-1.5	1-3	Ripples with the appearance of scales; no foam crests	0.1-0.2
2	Light breeze	1.6-3.3	4-6	Small wavelets; crests of glassy appearance, no breaking	0.3-0.5
3	Gentle breeze	3.4-5.4	7-10	Large wavelets; crests begin to break; scattered whitecaps	0.6-1.0
4	Moderate breeze	5.5-7.9	11-16	Small waves becoming longer; numerous whitecaps	1.5
5	Fresh breeze	8.0-10.7	17-21	Moderate waves, taking longer form; many whitecaps; some spray	2.0
6	Strong breeze	10.8-13.8	22-27	Large wave begin to form; whitecaps everywhere; more spray	3.5
7	Near gale	13.9-17.1	28-33	Sea heaps up and white foam from breaking waves begins to blown in streaks	5.0
8	Gale	17.2-20.7	34-40	Moderately high of greater length; edges of crests begin to break into spindrift; foam is blown in well marked streaks	7.5
9	Strong gale	20.8-24.4	41-47	High waves; dense streaks of foam and sea begins to roll; spray may affect visibility	9.5
10	Storm	24.5-28.4	48-55	Very high waves with overhanging crests; foam is blown in dense white streaks, causing the sea to appear white; the rolling of the sea becomes heavy; visibility reduced	12.0
11	Violent storm	28.5-32.6	56-64	Exceptionally high waves ; the sea is covered with white patches of foam; everywhere the edges of the wave crests are blown into froth; visibility further reduced	15.0
12	Hurricane	32.7-36.9	> 64	The air s filled with foam and spray; the sea completely white with driving spray; visibility greatly reduced	> 15

C) Wave Energy

Waves possesses energy in the form of:

1) Kinetic energy, energy inherent in the orbital motion of the waterparticles
2) Potential energy, possessed by the particles when they are displaced from their equilibrium position

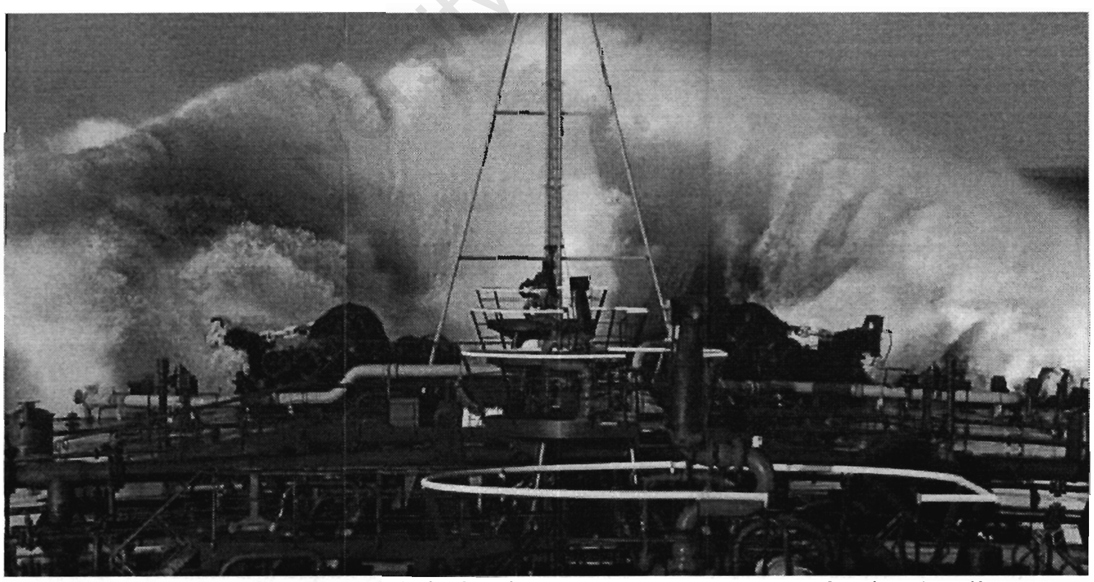
The equation $E = 1/8 (\rho \cdot g \cdot H^2)$ is the total wave energy per unit area, where:
ρ = Density of water (kgm^{-3})
g = Acceleration due to gravity (ms^{-2})
H = Wave height (m)
E = energy (Jm^{-2})

The wave power is the rate at which energy is propagated per unit length of the wave crest and is the product of group speed (c_g) and wave energy per unit area (E).

D) Extreme Individual waves (Rogue waves)

One of the big fears of shipping in the oceans around the globe is the existence of enormous waves that can reach a height more than 30 m. The highest recorded wave was 34 m and was recorded in 1934 in the North Atlantic. These rogue waves are the result of rare coincidences in wave behaviour.

"On average, in the open ocean one in the 23 waves will be over twice the height of the wave average, one in 1175 will be three times as high, and only one in 300,000 will be four times as high. The chances of truly monstrous waves are one in billions, but they do happen" (Thurman, 1997).



Picture 1: Supertanker Esso Nederlander meets a rogue wave in the Agulhas current (Photo L. Wolhuter)

One region, which is renowned for its rogue waves, is the region in the Agulhas current of the east coast of South Africa from roughly Port Elizabeth to Durban. In this region a very strong South westward current is flowing with an average velocity of approximately 1 to 2 m/s (Lutjeharms, 1983). Waves from storms in the South Atlantic are predominately propagating north eastwards, straight into the Agulhas current. This pattern will cause an increase in the wave height and it will also make the wave steeper and the wavelength smaller. Many ships have vanished or sank due to the rogue waves in this region (Mallory, 1974).

2.2 South African wave climate:

Due to the characteristic wind patterns of the region, the South Africa wave climate is essentially bi-modal. This climate comprises a dominant high-energy swell component generated by winds blowing over relatively great fetch over the south Atlantic to the south west of the continent, and lower energy wind seas, generated by local winds.

Some very distinctive wave regimes are present along the South African coast, which were characterized by Harris et al, 1972:

a) Those associated with a dominating low-pressure center (cyclones), situated in mid-latitudes. These, probably the most common systems, are usually characterised by a short west to east moving fetch at the north part of the low. When the low reaches a particular position it gives place to a long and frequently broad fetch from the south west. These lows cause the highest waves around Cape Town and the Agulhas Bank.
b) Those associated with long straight isobars slanting from the north west, giving rise to a fetch of a thousand miles or so, and perhaps arising from cyclogenesis in lower latitudes.
c) Those associated with the short north east fetch of the coastal lows, which seem to generate primarily high-frequency waves.

2.2.1 Wave height and peak periods

Using a selection of simultaneous Waverider records, Rossouw (1989) showed that the offshore wave climate along the westerly and southerly coastlines (Oranjemund to Port Elizabeth) display a similarity in significant wave height (Hmo) and Peak Period (Tp) during storm events. Wave heights offshore, along the south west and south coasts, up to Port Elizabeth, displayed nearly identical Hmo and Tp with peak periods ranging between 9 s and 16 s during 80% of the time (with median 12.5 s). A gradual reduction in wave height and period were found moving northwards up the west and east coasts. (See Fig 2, van der Westhuyzen 2002)

Table 2: Typical values for deep-sea wave lengths along the South African coast calculated with the deep water equation, $\lambda = g \cdot T^2 / 2\pi$ (with $g = 9.8\ ms^{-2}$)

T (s)	6	8	10	12	14	16	18
Cg ($kmhr^{-1}$)	16.8	22.5	28.1	33.7	39.3	44.9	50.5
λ (m)	56	100	156	225	306	399	505
H	Values can vary from 20 cm up to 30 m						

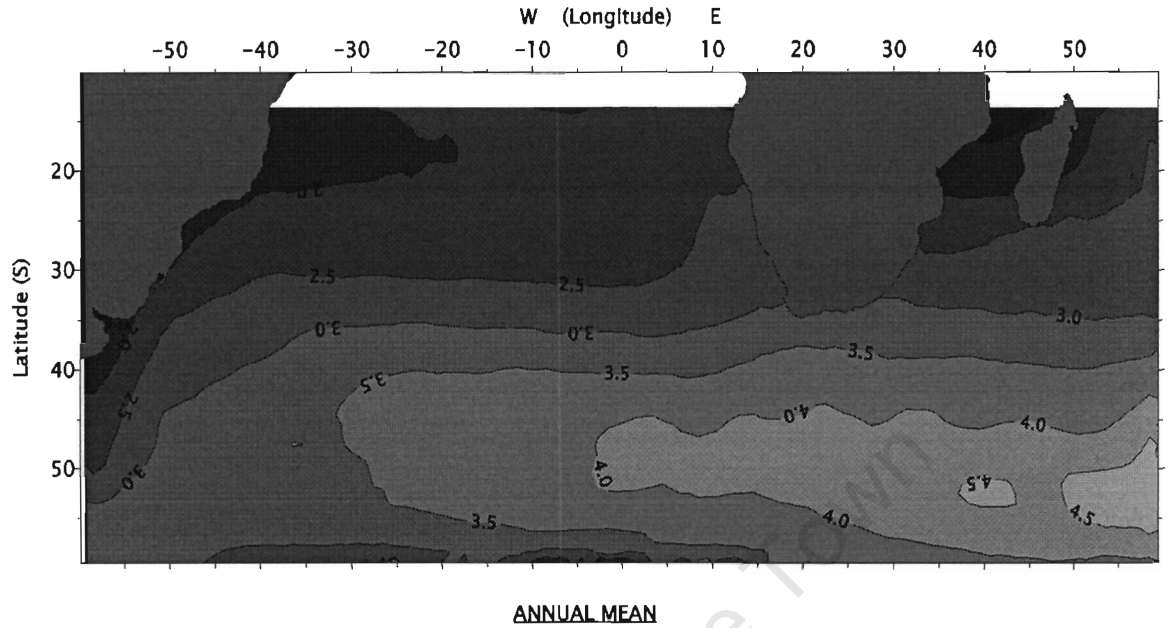


Fig 7: Mean wave climate for the South Atlantic (Rossouw M. & Rossouw J., 2001)

Rossouw (1989) found that similar wave conditions exist on the west and south coasts. The gradual reduction in wave heights along the west coast was caused by the decreasing intensity of the passing depressions with increasing distance of the center of the storm. Wave heights along the east coast were also found to decrease with increasing distance from the passing depressions, but are also influenced by weaker local systems.

2.2.2 Spectral shape

The average wave period along the South African coast is of the order of 8 to 16 seconds. However the individual wave periods in a wave spectrum are of the order of 6 to 25 seconds (Joosting, 1963). It should be noted that the wind cannot generate waves with peak periods of more than about 25 seconds.

Two years of measured spectra at Slangkop and Sedco-K (similar location as FA Platform) were used by Rossouw (1989) to formulate an average energy density spectrum. Although great variation was reportedly found in spectral shape, the spectral component of maximum energy occurred between 13 s and 16 s, with a frequency range of 0.06 – 0.08 Hz. According to Rossouw, this energy range applies for swell along the entire South African coast.

To get an indication of the typical shape of the spectrum, the spectra of 43 records of extreme wave events (Hmo > 6m) at Slangkop were analysed. These spectra fitted the JONSWAP spectral shape (Hasselman et al., 1973) with the value of peak enhancement factor γ ranging between 1 and 6, with a mean value of 2.2 and a standard deviation of 1.0 (Rossouw, 2001).

Due to the wind-wave generation near the coast, spectra are often found which to display a secondary, higher-frequency peak. This peak represents a growing wind sea state, which is superimposed on the ambient high energy swell, and gives the spectrum a bi-modal character (van der Westhuyzen, 2002).

2.2.3 Wave directions

The mean directions of waves of the South African wave climate are given in Fig 3, using the VOS dataset of 1960-2000 (van der Westhuyzen, 2002). The wave roses presented in Fig 3 include both wind waves and swell. However, it should be noted that VOS directions tend to be somewhat biased towards wind-wave directions (Rossouw, 2001). In general, the wave directions correlate well with the local wind climate, while a consistent south westerly component is added by high energy swell. This distinctive bi-directional nature of swell and sea components adds to the bi-modal character of the South African wave climate (van der Westhuysen, 2002).

In Fig 3 it can be seen that along the west coast, southerly seas dominate with a strong south westerly component. Along the south west coast, wave directions from the west to south east are recorded, with south direction slightly dominant. Along the south coast, south west swell dominates, but wind seas are present from both west and east directions. Along the south east coast wave directions from west to north are recorded, but the south west swell is dominant. Along the east coast, the dominant direction is southerly, although directions from south west to north are present.

2.3 Weather patterns of Southern Africa

The general weather patterns of Southern Africa and the oceans surrounding South Africa are responsible for the extreme wave events along the South African coast. Therefore, an introduction of the weather of Southern Africa and the predominant weather types responsible for the extreme wave events have to be reviewed.

Incoming solar radiation is the dominant external energy source, which is responsible for the general circulation of the atmosphere and oceans. The distribution and transformation of the incoming solar energy are complicated processes and will not be discussed further in detail. An example of directly driven circulation in the ocean is the thermohaline circulation. This relatively slow circulation is due to the cooling of surface waters in high latitudes. The wind driven circulation, which consists of indirect driven motions, arises from ocean-atmosphere interaction in the form of transferring heat (and water vapour) between the ocean and atmosphere (Summerhayes & Thorpe, 1996). This transferring of heat is responsible for the formation of depressions and anticyclones, which are the main cause of severe weather and extreme waves.

Macro-scale weather patterns for the South African region are the two anticyclones on the Atlantic Ocean and Indian Ocean. These two almost permanent anticyclones are due to the so-called Hadley circulation. Warm air in the tropical region rises and descends at around 30° S. Hadley cells play a significant contribution in energy exchange caused by the deficit in incoming solar radiation between the poles and tropics (Preston-Whyte, 1993).

In all seasons the dominant feature of the general macro-scale circulation of the atmosphere is the large tropospheric circumpolar vortex of westerly winds (Ferrell westerlies). These westerly winds reach their maximum in the upper troposphere (Jet stream) (Preston-Whyte, 1993).

Disturbed air in the Ferrell westerlies creates low pressure systems, which move from west to east, south of the two high pressure systems, with intervals of about three to five days. The windfields associated with the west to east moving low pressure systems are the main sources of the higher-energy wave climate to which the south African coastline is exposed (van der Westhuyzen, 2002).

Two distinctive weather patterns are found for winter and summer. During winter the South Atlantic high and South Indian Ocean high systems are situated around 30° S latitude. Depressions from the Ferrell westerlies, with their associated cold fronts, pass with regular intervals, along the latitude 40° S beneath the two anticyclonic systems just south of the African continent (Preston-Whyte, 1993).

In the southern ocean the passing low-pressure systems result in strong south westerly winds, which generate swell over long fetches to the south west of the African continent. Wind conditions along the coastline undergo a characteristic pattern change during this passing. Due to the clockwise (cyclonic) rotation of the passing depression, winds on the west and south coast change from an initial north west, through west to south west. When reaching the east coast, the depression is normally deflected by the south Indian high and moves southward, away from the continent. The local wind climate along the coast is presented in Appendix 1 and is in general agreement with the description of underlying weather system.

During summer months, the whole system of high and low pressure moves southwards, with the south Atlantic high and south Indian high residing between latitudes 30° S and 40° S. The belt of the Ferrell westerlies is pushed to the south, so that the influence of the passing depressions will have a lesser influence on the coastal regions (Taljaard, 1967). However the presence of the anti-cyclonic South Atlantic high results in southerly to easterly winds along the west and south coasts.

Weather conditions along the east coast are less regular than those of the west and south coast. It was observed that east of Port Elizabeth the influence of regularly passing cold fronts of the Ferrell westerlies is less intense (Hunter, 1987). This was presumed to be due to a combination of decreasing intensity of cold fronts east of Port Elisabeth, the deflection of the depressions by the south Indian high and the north-eastwards swing of the coastline to the east of Port Elizabeth (Hunter, 1987).

The distribution and the wind regime over Southern Africa are in many respects completely different in summer and winter (Taljaard, 1995). The subtropical high-pressure belt at sea level is displaced northwards by five degrees of latitude from summer to winter on both sides of the land. Anticyclonic circulation predominates up to about the 700-hPa level over the land in winter, where after at higher levels almost due westerlies take over south of 15° S. The lower-level anticyclones on land are interrupted once to twice a week by cold-front troughs associated with the passage of the waves in the westerlies of the middle and upper-troposphere.

Differences between summer and winter atmospheric circulation (Taljaard, 1995):

1) The subtropical high-pressure belt shifts about four degrees of latitude northward in winter, allowing the enhanced westerlies to impinge the West Coast south of about 27° S.
2) The upper westerlies increase in strength and expand more than 5 degrees equatorward.
3) The monsoonal low-level trough which extends from northern Namibia to north eastern Cape in summer is replaced by predominantly anticyclonic circulation in winter.
4) Subsidence is greatly enhanced except intermittently over the south-western coastal belt, so that temperature inversions separating dry subsided air from shallow maritime or destabilised continental air increase and intensify.
5) The ITCZ (Inter Tropical Convergance Zone) with its associated humid tropical air disappears from the scene.
6) The trade-wind current astride and across Madagascar, which transports humid tropical maritime air to the subcontinent in summer, reverts to a broad south easterly stream bypassing the eastern fringes of land in winter.

What follows are synoptic situations important for the generation of extreme wave events along the South African coastline. Examples of the synoptic weather charts can be found in Appendix VII.

2.3.1 Cold fronts

The disturbed air in the Ferrell westerlies cause the low-pressure systems with their associating cold fronts. As with the trough and ridges of the upper troposphere, their surface counterparts, the individual wave depressions, cold front troughs and the anticyclones, do not regularly conform to standard patterns but they vary in intensity, shape, speed of propagation and the tracks followed (Taljaard, 1995). The great majority of the wave depressions occur well to the south of 40° S. Their associated cold fronts sweep over the southern part of the continent one or twice a week.

These cold fronts interrupt the usual monotony of the stable weather associated with the presence of the dominant anticyclones. The temperature difference, associated with a cold front, is called a cold snap and can result in a difference of 10 degrees.

It is well known that atmospheric wave cyclones of the southern hemisphere are most densely clustered in the middle latitudes (45°-65° S) and that their frequency diminishes northward so that very few occur north of 30° S. South of 35° S the systems occur evenly scattered but the dense clustering starts south of 45° S (Taljaard, 1967).

The atmospheric wave cyclones develop or pass by about twice per week within less than about 800 km off the South African coast and when they are intense they can produce severe weather and extreme waves along the coastal belts. Analysis by Harrris et al (1972) of the pressure distribution for 1971 suggests that the fronts pass the Cape with an average periodicity of about 3 to 4 days. Van Loon (1967) estimated the average speed of fronts between 30° and 40° S as 36.9 $kmhr^{-1}$ and 40.5 $kmhr^{-1}$ for summer and winter respectively.

2.3.2 Cut-off lows

Another cold core depression or westerly trough is the cut-off low, which starts as a trough in the upper air westerlies. Then it deepens into a closed circulation extending downward to lower heights and becomes cut-off from the Ferrell westerlies (Preston-Whyte, 1993).

Table 3: Monthly frequencies of Coastal Lows during a 10 year period from 1973 to 1982 (Taljaard, 1985)

Month	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Frequencies	6	3	9	14	12	8	10	10	13	9	8	4

It is important to note that their location, direction and speed of the associated onshore and offshore winds are vital for the weather experienced over the coastal belts (Taljaard, 1996).

Most of the cut-off lows have life spans between two and up to five days over land or within short distances from the coast.

The following features of cut-off lows are significant (Taljaard, 1995):

- The most favourable condition for their development is the eastward advance and intensification of an anticyclone well south of the axis of the subtropical high pressure belt, i.e. along about 40° S from Gough Island to a position north of Marion Island.
- The lows are associated with more precipitation during their development stages when they are baroclinic than when they reach maturity or thereafter when they become barotropic.

There are no obviously favoured spots for cut-off lows to develop, nor do they follow preferred tracks. Although some systems develop of the west coast and then move onto the land, they mostly develop somewhere over the land and than move out over the east and south coasts. Onshore south easterly winds accompanied by heavy rain is called a " black south easter" (Taljaard, 1996). These strong south easterly winds are associated with extreme wave events with an easterly direction.

2.3.3 "Explosive" cyclogenesis

Cyclogenesis is referred to as the generation phase of a cold front, where the center pressure drops.

An explosive cyclogenesis is a low pressure system with an average central pressure drop of 1 mb/hour for 24 hours (Sanders and Gyakum, 1980). Most of the time these so called "bombs" are a result of intense SST (Sea Surface Temperatures) gradients, which trigger the explosive cyclogenesis in the same way as tropical cyclones (Hunter, 1987).

Taljaard (1967) investigated the distribution of cyclogenesis in the Southern African zone between July 1957 and December 1958. He discovered a significant summer concentration near 45° S, 0°-10° E. Satellite images showed warm cored eddies with high energy. Pandolfo (1985) came to the conclusion that the retroflection zone in the Agulhas current might favour the generation of cyclonic potential vorticity.

2.3.4 Coastal lows

Coastal lows develop when synoptic scale flow and the escarpment of the coastline interact and when there is a sharp drop in altitude towards the coast. As the air descends to the coast, cyclonic vorticity is generated and coastal lows form.

Propagating speeds are seen to range from 25 $kmhr^{-1}$ (6.9 ms^{-1}) to 90 $kmhr^{-1}$ (25 ms^{-1}) with propagating paths mostly from the west coast to the south coast, following the coastline as trapped internal Kelvin waves (Hunter, 1987). The coastal lows are always confined to coastal areas and have a pressure that seldom is deeper than 850 hPa (i.e. about 1500 m) (Preston-Whyte, 1993).

Coastal lows form at any locality along the coast between Namibia and northern Natal, provided that strong offshore winds prevail (Preston-Whyte, 1993). Particularly on the east coast coastal lows occur due to the topography, the local generation of cyclonic vorticity and the regular features of the circulation of the coastal region (Preston-Whyte, 1993). Coastal lows occur every few days along the west, south and east coasts and they are associated with very characteristic changes in the weather. All coastal lows produce a warm offshore airflow ahead of the system and a cool onshore airflow behind the system. Coastal lows cannot be associated with large-scale rain producing systems, as the cold front, and seldom travel inland.

Coastal lows are not responsible for extreme wave events on the west coast, but mostly on the east coast, where a cool onshore airflow behind the system causes strong north easterly winds, which will enhance wave action.

2.3.5 Tropical cyclones

The ITCZ migrates to a mean position between 10° and 20° S in the south western Indian Ocean during southern summer. The tropical cyclones develop along or close south of the ITCZ and then migrate westwards and finally southwards, mostly east of Madagascar but about a third of the systems cross this obstacle or even bypass the island to its north. A small number of systems develop in the Mozambique Channel starting out as tropical lows. Most of the systems are centered 500 km or more from the east coast but when they approach the land within less than 200 km, onshore south easterly winds will develop (Preston & White, 1993)

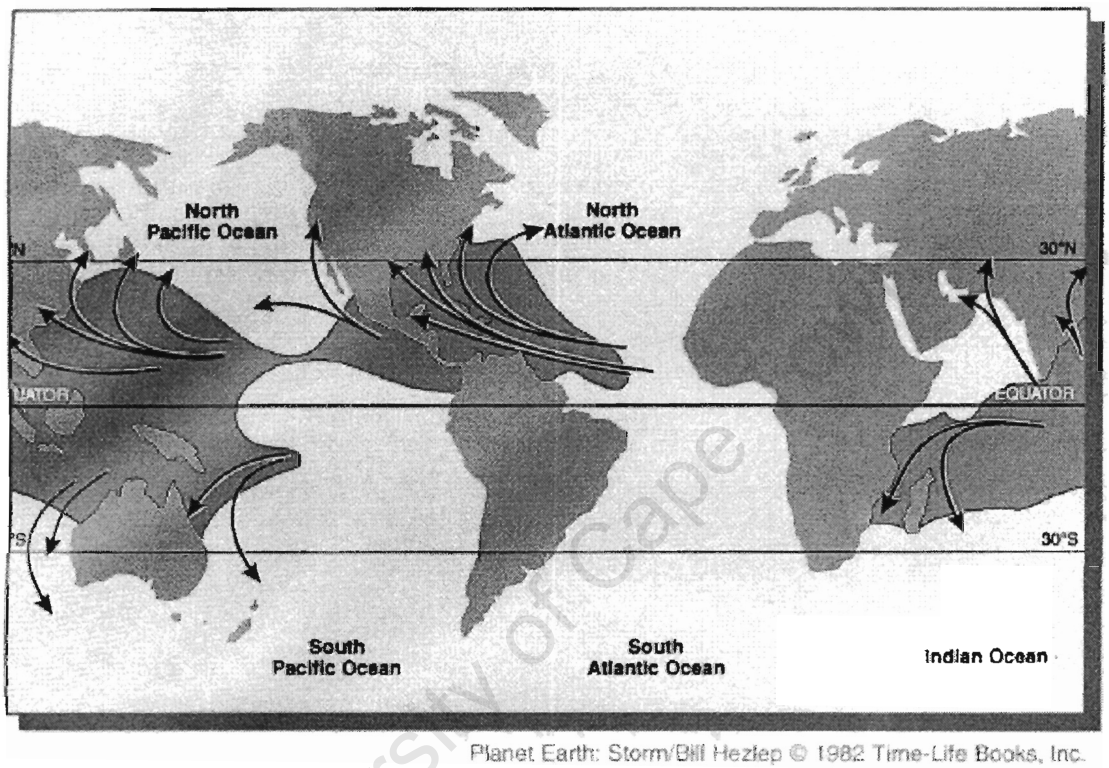


Fig 8: Frequent cyclone source regions and their tracks (Time life books, Inc, 1982)

Tropical cyclones, in contrast to the southern Cape cold fronts, have occurrences and paths that are erratic and unpredictable. Tropical cyclones are much more intense and smaller than the cold fronts and have specific source regions (See Fig 8). Fig 8 shows that only the northern KwaZulu-Natal coast is influenced by these cyclones. However these systems can cause high waves along this part of the coast.

The typical tropical cyclones have a diameter of about 650 km. Sea level pressures may drop to 900 hPa and even below. Some specific features for the initiation of a tropical cyclone, is an extensive ocean area with sea surface temperatures (SST) greater than 27° C, are required (Preston-Whyte, 1993).

In the Australian/ Indian/ and Pacific region, 97 percent of the tropical cyclones form in the Monsoon through between the equatorial westerlies and the tropical easterlies. The warm core eye of a tropical cyclone, which is in the order of 30 to 50 km in diameter, is vital to the growth and maintenance of cyclones. Cyclones mainly occur in summer and autumn (Preston-Whyte, 1993).

An important factor in the description of the east coast climate is the presence of tropical cyclones, as highlighted by Rossouw (1999). Rossouw concludes that at coastal locations between latitudes 25° S and 32.5° S, tropical cyclones occur with a return period of one in a hundred years.

2.4 History of wave recording in South Africa

Since 1854 wave data has been collected around the South African coast. Voluntary Observing Ships (VOS) are the first source of wave observations along the coast of South Africa. These visual observations include wave height, period and direction, and were mainly made by merchant ships travelling around the coast of South Africa.

In a later stage observations were increased with a variety of instruments including clinometers, ship borne wave records, pressure meters, inverted echo sounders and accelerometer buoys. Accelerometer buoys became the most standard as far as wave recordings is concerned.

From 1964 to 1974 additional wave recordings were made by research ships, such as the Africana II, Thomas B Davie and Meiring Naudé. These ships made use of NIO ship-borne wave recorders. The weather ship F H Hughes made use of a Boersema recorder and was later replaced by a NIO recorder. All these recorders are accelerometer type of instruments.

In the period from 1961 to 1970 the most important recorder was the clinometer, which increased in number from one 1965 to twelve in 1970. The clinometer stations remained operational until 1974.

Some new techniques were evaluated to attempt to increase the accuracy of wave observations by instruments. In 1969 a new imported accelerometer buoy was installed at Mossel Bay. This Datawell Waverider buoy manufactured in Holland seem to be superior to any of the wave recorders used previously and between 1971-73, the number of stations increased from 1 to 7. Recordings were taken for 20 minutes every six hours and than processed to analogue form on paper rolls. Analysing the data had to be done by hand and was very labour intensive. This lasted till 1976 when the first digital recorder was installed at Slangkop of the Cape Peninsula.

In 1980 the Institute for Maritime Technology (IMT) and the National Institute for Oceanology (NRIO CSIR) produced a computer program to analyse and check wave recordings for quality (Rossouw et al, 1982).

Until 1992, 66 Datawell waveriders had been imported into South Africa, but due to money constraints and political problems these buoys were replaced by a locally developed wave recording buoy called the Wavemonitor. Also a directional wave buoy called the 3D buoy was developed. This buoy does not use accelerometer type sensors, but Differential Global Positioning System (DGPS) technology (Davies et al, 1997).

During this period real time systems to receive and display the data were put in place. This was the basis for the South African wave-recording network, as it exists today. The network consists of a number of components:

1) The wave recording instrument
2) The base station on shore (PC that receives wave data from the buoy and stores or transmits the information to the central station)
3) The central station at Stellenbosch (receiving, processing and archiving wave data from all base stations)

At present the network compromises of five base stations, which are listed below:

Table 4: Network of wave station along the coast of South Africa (Rossouw et al, 1999)

Location	**Type of Instrument**	**Water depth (m)**
Entrance of Saldanha Bay, West Coast	Wavemonitor buoy	20
Off Cape Town, South-west coast (Slangkop)	3D buoy	70
Off East London, South-east coast	3D buoy	23
Off Durban, East coast (until 2001)	Wavemonitor buoy	50
Durban harbour entrance (from 2002)	ADCP	16
Off Richards Bay, East coast	Wavemonitor and 3D buoy	23
Mossgas FA Platform off Mossel Bay	Marex radar system	100

ADCP = Acoustic Doppler Current Profiler

Safe and efficient port operations are getting increasingly important, therefore the Integrated Port Operation Support System (IPOSS) was put in place. This system not only provides wave information but also information on winds and tides in the vicinity of the harbour. The IPOSS system offers guidance to NPA marine staff on the safe operation of ships, especially under normal and extreme conditions.

2.5 Design wave heights for the South African coast

A variety of methods and recommendations have been published on extreme wave analysis in the past. But it appears that there is no standard procedure for estimating extreme waves, although some recommendations have been published (Mathiesen et al, 1994).

The method for estimating extreme or design waves heights for South Africa is the method of moments to fit a two-parameter Extreme-I (Fisher-Tippett I) probability distribution to a total sample from the winter months. The two parameters are based on the mean wave height and its standard deviation. This method provides stable estimates, especially for the Southern Atlantic Ocean (Rossouw, 1989).

The most likely peak period for the 100-year wave height of the RSA stations was estimated to be approximately 16 s, as referred to in Table 5 (Rossouw & Rossouw, 1999).

Table 5: Estimation of Tp for 100 year design wave height, according to Rossouw J. & Rossouw M., 1999.

Station	100 year Hmo (m)	Most likely Tp (s)	Range: 95% confidence band	Lower limit: Teng et al (1994)	Range: DNV (1977)	Range: Carter et al (1986)
Slangkop	11.6	16.1	12.1-20.1	13.3	12.3-18.7	14.2-15.9
Agulhas Bank	12.2	16.1	12.1-20.1	13.6	12.6-19.2	14.5-16.3
Port Nolloth	9.3	16.1	12.1-20.1	12.0	11.0-16.8	12.7-14.3

Three different methods, Teng et al (1994), Det Norske Veritas (1977) and Carter et al (1986), are used to estimate Tp from the extreme wave height.

Rossouw (1989) provides an important review of the wave climatology along the South African coast. His study originated out of the need for consolidation of all the available wave information along the South Africa coast to enable proper selection of deep-sea wave conditions for the design of structures along the coastline. The aim of his study was to do a systematic check of all the wave data available on accuracy and reliability. He also studied weather patterns responsible for generating large waves along the coast and gave a few examples of storms.

With this information, Rossouw compiled design wave heights for the African coast, which are used in this thesis to set up the criteria to identify the extreme wave events (Refer to § 3.2.1 Criteria for extreme wave events)

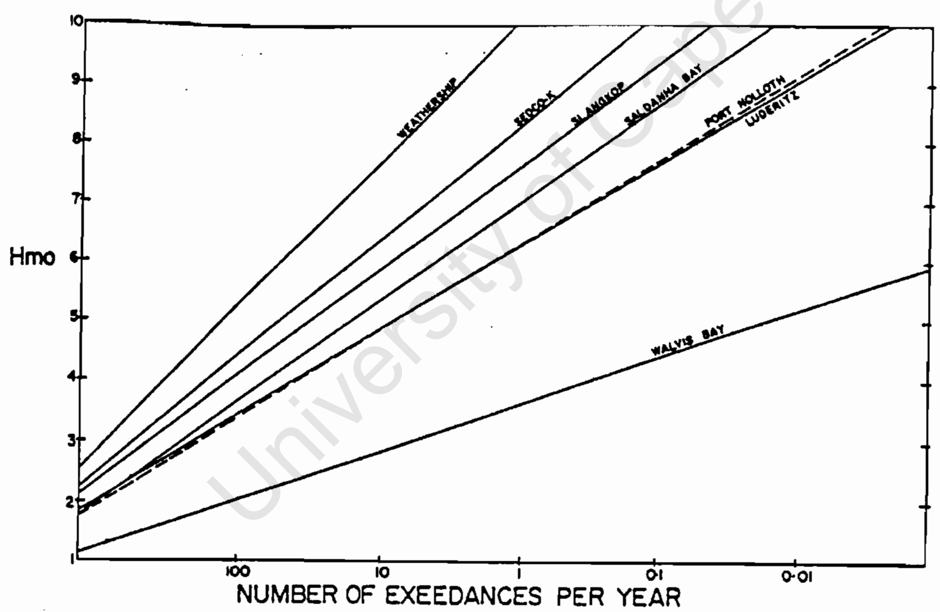


Fig 9: Design wave heights along the west coast (Rossouw 1989)

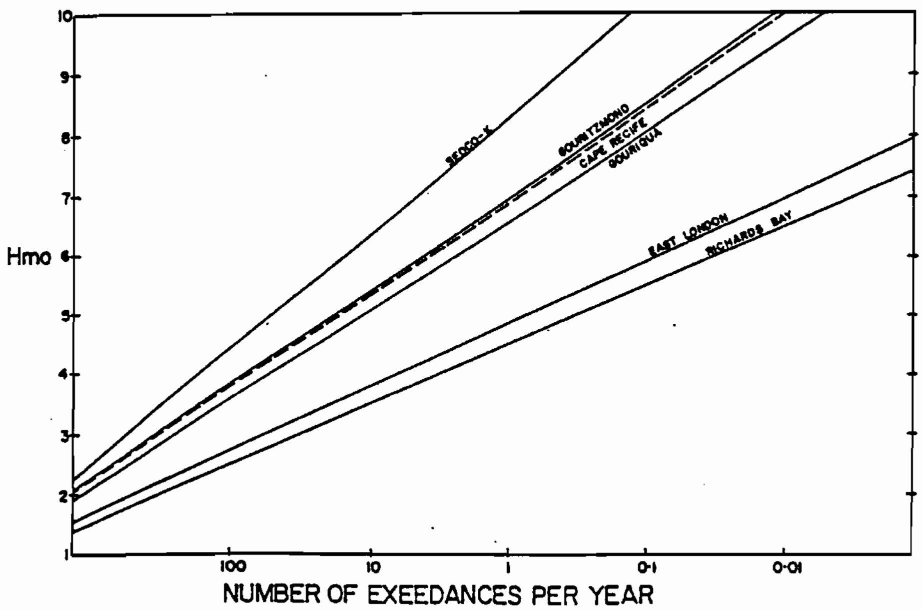


Fig 10: Design wave heights along the south coast and east coast, it has to be noted that Sedco-K is approximately equivalent to FA-Platform (Rossouw, 1989)

Chapter 3: Material and Methods

This chapter will describe the instrumentation used to record the wave measurements and all the methods that were used to analyse the dataset and weather patterns. Firstly, locations of the wave measurement instrumentation are given, together with criteria that were set up to identify all extreme wave events.

3.1 Materials

3.1.2 Instrumentation & locations

At present six permanent wave recorders are located around the coast of South Africa. It is chosen not to include Saldanha Bay for this thesis because observations taken by this wave recorder are considered to be influenced by the channel configuration at which the instrument is located. The dataset recorded by the wave recorder in Durban is not included either due to the inconsistency of locations and therefore depths. Another reason is that both Saldanha and Durban do not measure wave directions. And finally Saldanha and Durban are only operational since 2000 and 1998 respectively and therefore do not form a long enough database for comparison with other locations.

Slangkop/ Cape Point has been operational for more than 20 years and forms the basis of the dataset. Because of damage and the replacement cost of missing and stolen buoys from the Slangkop location, the new Waverider buoy from 1994 onwards was placed in a new location, out of the shipping line. The reduced depth from 170 to 70 m only influences the reading of wave heights marginally by 1 to 2% (transitional waves). Only at a depth of around 50 m will the readings be influenced significantly.

The FA-Platform is an important location for wave measurements to research the wave climate on the Agulhas Bank and for correlation with Slangkop. To distinguish between south westerly and easterly events, East London is an important location to study the rate of diminishment of wave heights when rounding the southern Cape.

The long duration of wave recordings at Richards Bay is an important record for looking at weather patterns responsible for extreme wave events on the east coast. Since 2000, Richards Bay also records wave direction, which is important for determining the origin and impact of events.

A1) Slangkop buoy:

Station code: SL01-SLANGKOP
Latitude: 34.12666 S
Longitude: 18.17666 E
Waterdepth: 170 m
Data range: 1979-01-01 to 1993-12-31
Instrument type: 1979-1993 Non-directional Waverider

A2) Cape Point buoy:

Station code: CP01-CAPE POINT
Latitude: 34.0.204 S
Longitude: 18.0.28667 E
Waterdepth: 70 m
Data range: 1994-01-01 to 2003-10-31

Instrument type:	1994-1995	Wave monitor
	1995-1996	Waverider
	1996-2000	Wave monitor
	2000-2001	3D Directional Buoy + Wave monitor
	2001-2004	Directional Waverider

B)FA-Platform (Agulhas Bank):
Station code: FB01-FA PLATFORM
Latitude: 34.97 S
Longitude: 22.17 E
Waterdepth: 113 m
Data range: 1979-01-01 to 2003-12-31

Instrument type:	1996-2003	Marex (non-directional vertical radar sensor)

C) East London buoy:
Station code: OL01-EAST LONDON
Latitude: 34.04 S
Longitude: 27.925 E
Waterdepth: 22 m
Data range: 1992-01-01 to 2003-12-31

Instrument type:	1992-1993	Waverider
	1993-2001	Wavemonitor
	2001-present	3D Directional buoy

D) Richards Bay buoy:
Station code: RB01-RICHARDS BAY
Latitude: 28.0.8265 S
Longitude: 32.0.104 E
Waterdepth: 22
Data range: 1979-01-01 to 2003-12-31

Instrument type:	1984-1994	Waverider
	1994-2000	Wavemonitor
	2000-present	3D Directional buoy

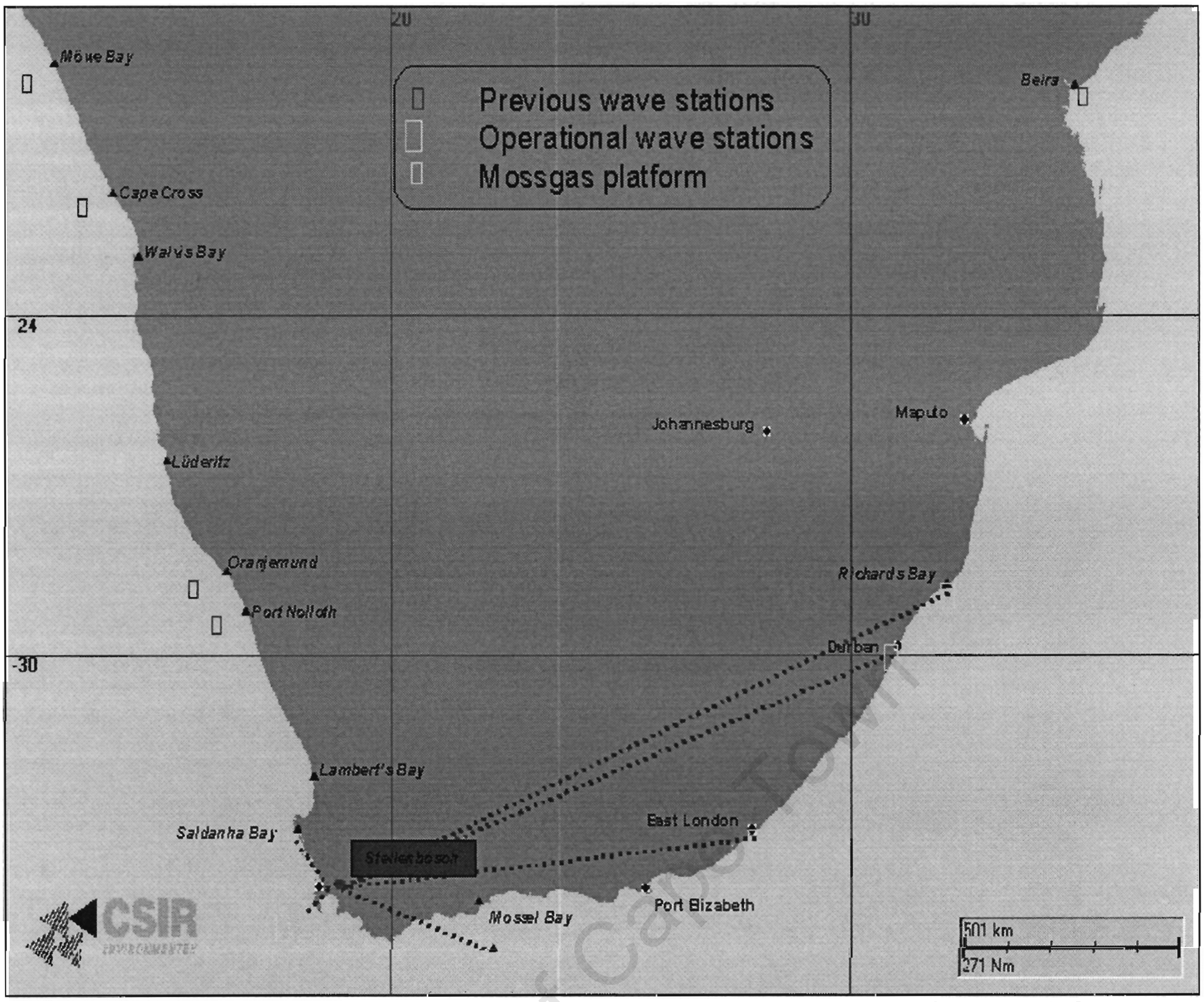


Fig 11: Locations of CSIR wave recoding network (Most southerly locations are, left Slangkop and right FA-Platform.

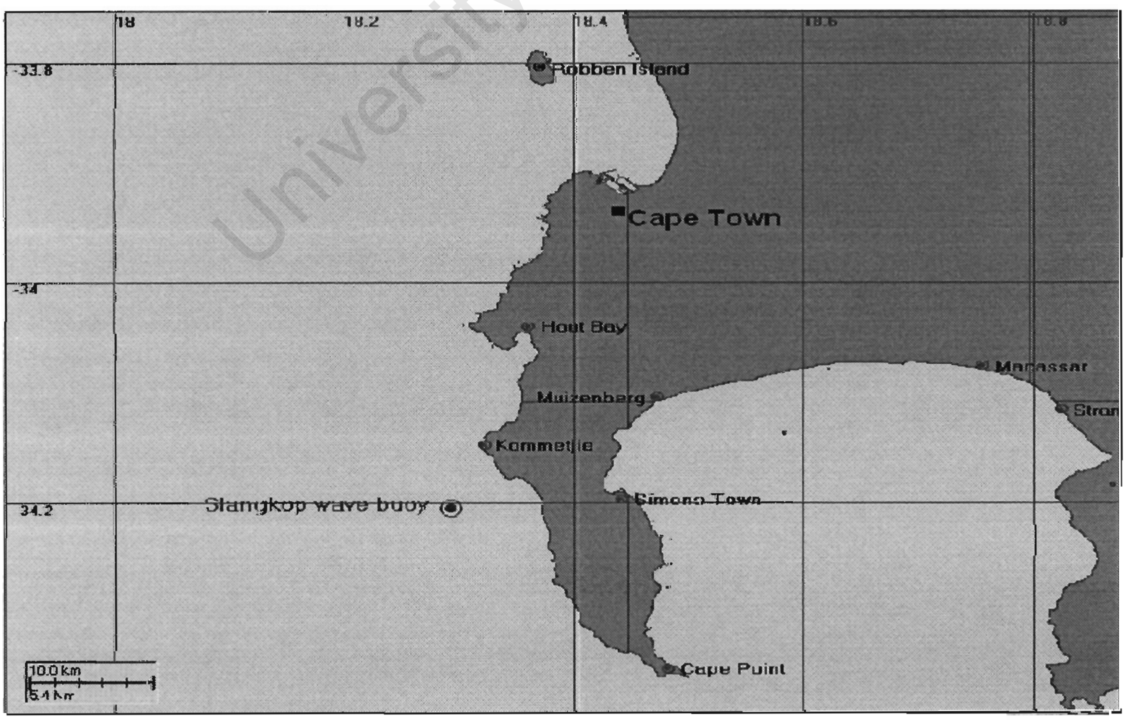


Fig 12: Location of Slangkop buoy

3.1.2 Description of Instrumentation

Directional waverider MK II:

The Waverider buoys are imported from the Dutch company Datawell. For more information about Waverider buoys see www.datawell.nl. Waverider buoys make use of the accelerometer system where the vertical acceleration are double integrated to produce the displacement of the buoy. The displacement is proportional to the wave heights. The sampling interval in South Africa is set, as in most countries where waves are recorded, as 0.5 s (Rossouw, 1989).

- Measures wave height for wave periods of 1.6 to 30 seconds, accuracy 3 % of measured value
- Measures wave direction
- Measures water temperature
- 0.9 m diameter spherical hull of AISI 316
- Optional Cunifer hull, warranted not to corrode
- Low power: operational for 12 - 30 months, depending on the configuration
- HF transmitter range 50 km over sea
- Optional Argos transmitter for ocean wide coverage and unlimited range
- Optional Orbocomm module (incl. GPS module) for two-way communication with buoy, independent of global position
- Optional GPS module for buoy monitoring and tracking through HF link (optional internal logger)

Datawell Waverider:

- Measures wave height for wave periods of 1.6 to 30 seconds, accuracy 3 % of measured value
- Optional water temperature sensor
- 0.7 m or 0.9 m diameter spherical hull of AISI 316
- Optional Cunifer hull, warranted corrosion protection
- Low power: operational for 10 - 20 months, depending on the configuration and hull diam.
- HF transmitter range 50 km over sea
- Optional Argos transmitter for ocean wide coverage and unlimited range

Wavemonitor:

In 1993 a local manufactured accelerometer came into operation. This is the Wavemonitor, which has similar features as the Waverider as explained above.

Differential GPS buoy (3D buoy):

This buoy is developed by the CSIR and has a similar construction as the Waverider. Instead of an accelerometer this buoy has a differential Global Positioning System (GPS) unit that provides the absolute position of the buoy (Davies et all, 1997). Every 17 minutes at regular intervals the position of the buoy is recorded by GPS, which need at least four satellites to obtain an accurate position (Rossouw, 2000).

The dual-frequency receiver used with the GPS system is a unique feature of this buoy and will have a much shorter recovery time when a wave breaks over the buoy and cut of its signal (Rossouw, 2000).

Tides and long period waves can be correctly recorded by this instrument due to the transfer function that remains the same over the complete dynamic frequency range and measures the absolute position. Accelerometer buoys start to intensify waves with period greater than 20 s (Rossouw, 2000).

The buoy uses GPS and therefore it can be tracked when it travels from its original position.

Marex:
The Marex S120 Environmental Monitoring System is a meteorological and Oceanographic data collecting and processing system, which displays the outputs of a variety of sensors in easily readable form. Two display racks based upon a Z80 microprocessor enables them to collect, process, display and transmit data. Marex operates automatically and only the clock and sensor details on commissioning have to be initialised.

The meteorological rack will not be discussed in detail. The oceanographic rack acquires tide and wave shape from a Wavemonitor.

The sensor used is the I.S. Wavemonitor and is a radar device that scans down from its mounted position to the sea beneath. The device works by sending out radar waves and timing the delay before each reflected wave is received. This time delay is converted to a voltage signal proportional to the distance between the sensor and sea surface. The maximum range of the device is 50 m and minimum is 7 m.

The instaneous wave height is continuously output to a "raw" wave profile. This data is stored in a buffer, and sampled at 2Hz commencing on every 20-minute boundary. When 2048 wave height values have been accumulated, the information is processed to derive the various wave parameters. The parameters include significant and maximum wave heights (Hs or Hmo and Hmax) and the average zero crossing period (Tz) are permanently displayed. Front panel displays are updated every 20 minutes at the completion of a measurement cycle.

The derived data is presented in appropriate formats at each of the four serial output ports and can be used to drive a modem, printer, data logger or remote displays. Analogue voltage outputs of processed values are also provided.

3.2 Methods

3.2.1 Criteria for extreme wave events:

Before the extreme wave events can be analysed, they first need to be defined. M. Rossouw 2001, uses an Hmo of 6.0 m as the main criteria to identify an extreme wave event. Constraints in time caused that the criteria set up for this project were a bit tighter to exclude some of the lesser extreme events.

The criteria to identify extreme wave events for this study were mostly obtained by information from Rossouw 1989, design waves along the South African coast. In § 2.5 Design wave heights for the South African coast, a more detailed description is given, which includes Fig 9 and Fig 10 that were the basis for setting up the following criteria.

Slangkop/ Cape Point criteria:
According to design significant wave heights from Rossouw (1989) for the South African coast (Refer to Fig 9), the number of exceedances with a significant wave height greater than 6.5 m per year is circa 5. With a database from 1979 till 2003 (25 years) it is expected to find 75 events with Hmo greater than 6.5 m.

After analysing the 25 years database 53 extreme wave events were identified with a Hmo greater than 6.5 m.

Only 70% of these identified extreme wave events will be used in this thesis. The other 30% are not used for this study, because a single exceedance will not count as a whole event. Therefore it is chosen to use events, which are persisting for a period longer than 6 hours.

The events that did not meet the criteria were deleted and the total number of extreme wave events analysed for Slangkop is 33.

FA-Platform criteria:
According to the design significant wave heights from Rossouw (1989) for the South African coast (Refer to Fig 10), the number of exceedances with a significant wave height greater than 6.5 m per year is circa 8. With a database from 1996 till 2003 (8 years) it is expected to find 64 events with Hmo greater than 6.5 m.

After analysing the 8 years database 40 extreme wave events were identified with a Hmo greater than 6.5 m.

Only 80% of these identified extreme wave events will be used in this thesis. The other 20% is not used for this study, because a single exceedance will not count as a whole event. Therefore it is chosen to use events, which are persisting for a period longer than 6 hours.

A total of 32 events were identified as an extreme wave event.

East London criteria:
All events are taken with a Hmo greater than 4.5 m. Continuous recordings of wave measurements only started in 1992 and therefore all the events are analysed without taken the duration of the exceedance greater than 4.5 m into consideration.

Design wave heights from Rossouw (1989) state that the number of exceedances per year for East London is around 1 1/2 a year (Refer to Fig 10). For a 12 years dataset you would have 18 events according to Rossouw (1989) design wave heights.

The number of identified extreme wave events comes to a total of 18.

Richards Bay criteria:
According to Rossouw (1989) the number of exceedances a year for Richards Bay with a Hmo greater than 4.0 m is 5 a year (Refer to Fig 10). For a dataset of 20 years the total number of expected events will be 100.

Within these 20 years a 34 events were recorded with an Hmo bigger than 4.0 m. Another criteria for Richards Bay is that within 12 hours two or more recordings have to have a Hmo of 4.0 or greater than 4.0 m. After deleting the events that not met the criteria the number of events for Richards Bay is 17.

3.2.2 Quality control

Some errors in the data from the FA Platform were detected (See Table 6). The maximum wave height (Hmax) took extremely high or low values during some events. These recordings are impossible because the significant wave height does not change with the value of Hmax. It is possible to have Hmax recording twice or even three times as high as the significant wave height, but the changes for the likelihood of occurrence is extremely low. (Refer to 2.1 Basics of ocean gravity waves) These errors were only single data points and to resolve this the average between the surrounding data points was taken. These errors can be due to readings of the radar of sea spray during storms.

Table 6: Errors in the dataset

Station	**Date**	**Time**	**Data error**
Slangkop	1996-24-09	900	Tp 22.26 s
FA Platform	2002-07-27	1200	Hmax 45 m
FA Platform	2000-07-19	1900	Hmax 31.6 m
FA Platform	2001-05-04	1400	Hmax 0.2 m
FA Platform	2002-10-01	1200	Hmax 45 m

3.2.3 Missing Data

During some of the events some data was missing. Only major gaps in the dataset are noted below.

FA Platform:
1997-23-11 missing data

1997-10-7 1300 till
1997-10-8 1134 no data

1999-9-18 Last 13 hours are missing

2000-7-20 missing data (+ hours missing during event)

Slangkop:
1988-10-28 missing data

1989-04-01 missing data

1989-07-16 missing data

1990-7-14/15 missing data

Richards Bay:
1984-02-18 missing data

1991-08-02 missing data

1994-07-25 missing data

2000-11-20 missing data

East London:
1993-9-21 till
1993-9-23 missing data

1997-6-14 till 1800 missing data

3.2.4 Methods data analyses

After setting up the criteria the extreme wave events were identified, extracted from the database and analysed on characteristics and trends. The events were characterised by processing or analysing the data as follows:

- When do the extreme wave events occur?
- Making graphs of the characteristics
  1) Hmo (significant wave height in m)
  2) Hmax (maximum wave height in m)
  3) Tp (Peak period in s)
- The wave direction
- 24-hourly slope before the peak of the event for Hmo and Hmax
- Maximum 6-hourly slope for Hmo
- Duration of events
- Correlation between locations and events

It has to be noted that all the events where extracted from the database following the same methods. Every event was extracted 48 hours before the first recording where Hmo was greater than the set up criteria and 24 hours after the last recording where Hmo was greater than the set up criteria.

Methods for calculating slopes:
The datasets of most of the wave recorders, except for FA Platform, differentiate in time intervals of the recordings from year to year. The quantity of data recorded is minimal once every 6 hours, once every 3 hours and maximal once an hour. As a consequence of this differentiation, the mean slope is calculated 24 hours before the peak using the following equation (smoothing of data by fourth differences):

$H^1 (t = 3) = -2H (t = 1) – H (t = 2) + H (t = 4) + 2H (t = 5) / \Delta t \cdot 10$ (Lanczos, 1957)

H^1 = mean slope ($m \cdot hours^{-1}$)
H = Hmo (m) or Hmax (m)
t = time (hours)
This equation is the derivative to calculate an estimation of the mean slope at t = 3. With t = 5 at the peak of the graph. A requirement using this equation is that the data points need to have identical time intervals. Due to the fact that successive 6-hour intervals are taken to calculate the slope, some data points in the 3-hourly and hourly datasets are left out.

It therefore has to be emphasised that the calculation for the slope is an estimation. For calculating the mean slope and the standard deviation this method is still very useful and is a good indication of the slope in 24 and 6-hour intervals.

In some cases there were data-points missing to calculate the slopes. To minimize the estimation factor linear interpolation of the adjacent data-points was undertaken. One example is given below.

Example of Linear interpolation for missing data points:

Event 26 (2000/07/16 till 2000/07/20)

In the three hourly data there was data missing at 1200 hours. Through linear interpolation of the 2 adjacent data points the missing data point at 1200 hours is estimated.

Table 7: The two data points extracted from the dataset at 2000/07/18

Time (hours)	Hmo (m)	Hmax (m)
957	4.11	7.71
1257	5.85	9.3

Linear interpolation Hmo:

$y = ax + b$
$a = \Delta y/\Delta x \Rightarrow 5.85 - 4.11 / 1257 – 957$
$= 5.8 \cdot 10^{-3}$

b = one of two points inserted into equation $\Rightarrow y = 5.8 \cdot 10^{-3} x + b$ (957, 4.11)
$\Rightarrow 4.11 = 5.8 \cdot 10^{-3} \cdot 957 + b$
$b = - 1.44$

Result linear equation is:

$y = 5.8 \cdot 10^{-3} x – 1.44$

want to know y (= Hmo) when x = 1200 fill in
$y = 5.52$

Same procedure for Hmax:

$y = 5.3 \cdot 10^{-3} x + 2.64$
$x = 1200$
$y = 9.00$

Methods duration:
To determine the duration of each event the following criteria were set up.

Table 8: Duration of each event is determined, were the significant wave height (Hmo) is greater than the values below

Location	**Hmo > ….. (m)**
Slangkop	6.0
FA-Platform	6.0
East London	4.5
Richards Bay	4.0

3.3 Methods analyzing weather patterns

Secondly the characteristics of the synoptic weather systems responsible for the extreme wave events were analysed. This is done by looking at the 24-hourly weather bulletins from the South African Weather Service (SAWS) during each event.

During each event at each location the weather bulletins were analysed on:

Identifying the weather systems responsible for the extreme wave event
For each event the daily weather bulletins were analysed, depending on the exact time of measurements when the significant wave height was greater than the set criteria. In most of the cases the bulletin was analysed from the previous day, only when an event started in the evening the bulletin of the same day was analysed. This is because the bulletins are issued between 12.00 and 14.00 hours.

In the case when an event lasted for several days, all these days were analysed, because during some events more than one weather pattern was responsible for the extreme wave event. This happened mostly with cold fronts.

The center pressure
Center pressures were recorded during each event. In the case when an event lasted for several days, all the center pressures were recorded and the lowest is used for the distribution tables.

The velocity of the weather system responsible

Estimations of the velocity of the weather patterns is done by analysing the displacement of the centre in 24 hours. The distance is measured for all of the pronounced cold fronts at Slangkop and FA-Platform and than calculated by given distances to Gough Island and Marion Island.

Distance to Marion Island is approximately 2226 km (1391 nm) and the distance on the SAWS daily bulletins is approximately 11 cm. The average displacement of the cold fronts for Slangkop and FA-Platform was 5.1 cm on the daily weather bulletins issued by the SAWS, which converts to a speed of 26.9 knots. It has to be noted that individual velocities of cold fronts ranged between 1.5 cm (7.9 knots) and 8 cm (42 knots) in 24 hrs.

The track of these weather systems

The tracks of the weather patterns were analysed in which direction the displacement of the center was going in the days during and the day after the event. Its accuracy is not in degrees but in e.g. east southeastward.

Estimated swell direction

Swell directions were estimated by analyzing the isobars of weather patterns responsible for the extreme wave event. Special attention was paid to the fetch, the distance of adjacent isobars and the wind direction/ speed at fixed recording locations.

Chapter 4: Extreme wave events

In this chapter all main results of the data analyses will be given and all results that are important in a lesser extend are included as Appendices.

4.1 Identified extreme wave events

The following dates of extreme wave events were identified according to the criteria discussed in § 3.2.1 Criteria for extreme wave events. For more information on the identified events and to observe the specific characteristics, refer to Appendix II till Appendix V, where all the data is processed in graphs for each event at each location.

Table 9: Dates of identified extreme wave events

	Slangkop	**FA-Platform**	**East London**	**Richards Bay**
Operation dates	1979-2003	1996-2003	1992-2002	1984-2002
Event no.	**Date**			
1	1979/6/24-27	1996/6/12-19	1992/6/23-26	1984/2/15-18
2	1983/5/12-16	1996/9/2-8	1992/6-7/30-3	1984/4/25-28
3	1983/5/18-22	1996/9/23-27	1992/8/6-9	1987/9-10/25-1
4	1983/6/20-26	1997/6/20-24	1992/8/8-12	1990/10/16-22
5	1984/5/13-19	1997/6/23-27	1993/3/22-25	1991/6/12-15
6	1986/3/28-31	1997/8/4-8	1993/4-5/28-1	1991/8/1-5
7	1988/10/27-30	1997/10/4-8	1993/9/21-25	1994/7/24-27
8	1989/3-4/28-01	1997/11/19-23	1995/6/23-26	1995/4/8-12
9	1989/7/13-16	1998/4/6-9	1996/6/16-19	1996/3/2-6
10	1989/8/23-27	1998/8/12-16	1996/10/19-24	1997/5-6/29-1
11	1990/5/18-22	1998/9/22-26	1997/4/5-8	1998/6/5-8
12	1990/7/10-14	1999/6-7/29-2	1997/5/26-29	2000/5/11-15
13	1990/8/8-12	1999/7/15-19	1997/6/10-14	2000/11/12-15
14	1991/7/23-27	1999/8/1-5	2001/3/11-14	2000/11/17-20
15	1991/7-8/29-2	1999/9/15-18	2002/7/15-19	2001/7/22-25
16	1992/6/20-26	2000/7/16-20	2002/8/13-17	2002/7/17-21
17	1994/6/18-22	2000/11/19-23	2002/9/8-11	2002/9/9-13
18	1995/7/5-9	2001/5/3-7	2002/10/1-4	
19	1995/7/15-19	2001/5/24-27		
20	1996/6/13-18	2001/8/15-19		
21	1996/9/23-27	2001/8/19-23		
22	1997/6/20-24	2001/9/3-7		
23	1997/6/25-29	2001/9/8-12		
24	1999/8/1-4	2002/5/21-26		
25	2000/7/13-16	2002/6/16-20		
26	2000/7/16-21	2002/7/7-11		
27	2001/8/18-21	2002/7/14-18		
28	2001/9/3-7	2002/7/23-28		
29	2002/5/21-26	2002/7-8/31-4		
30	2002/6/16-20	2002/9-10/30-3		
31	2002/7/25-30	2002/10/1-4		
32	2002/7-8/31-4	2003/8/17-21		
33	2003/8/17-21			

A total of 100 events were identified according to the criteria for the four locations. 33 events were identified for Slangkop, 32 for FA-Platform, 18 for East London and 17 for Richards Bay.

4.2 Characteristics of extreme wave events

One of the main objectives of this study was to look at the characteristics of each individual event and to see if there are any trends (or differences) between locations and events. The graphs of each individual event are given in Appendix II till Appendix V and shows very clear differences in characteristics between events and locations.

4.2.1 Distribution of events

When looking at the distribution of events for every month (refer to Table 10) it will become clear that for Slangkop, FA-Platform and East London not one event occurred during the summer months December, January and February. The densest distribution for Slangkop occurs in the months June, July and August (winter) while at FA-Platform the distribution is denser in July, August and September.

Table 10: Distribution in percentages of number of events for each month

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Slangkop	0	0	5	2	15	24	27	18	6	3	0	0
FA-Platform	0	0	0	3	10	14	19	20	20	8	6	0
East London	0	0	11	8	8	25	9	17	11	11	0	0
Richards Bay	0	6	6	12	9	15	17	6	9	9	11	0

Rounding the south coast the distribution pattern is quite different. In East London the distribution is more evenly scattered over all months, with still a pronounced peak in June. But events not only occur in winter most of the time, they are also distributed in months adjacent to winter months. Moving further up the east coast the distribution gets even more scattered and events occur almost every month. With still a higher distribution of frequent events in June and July.

Fig 13 shows that the distribution of events in the winter months are the densest for all locations. It has to be noted that the frequency of events for East London and Richards Bay is respectively 18 and 17. These frequencies are quite small and might be slightly different when a higher number of events are researched. This is the same case for Slangkop and FA-Platform only in a lesser extend than East London and Richards Bay.

When analysing seasonal patterns the distribution at Slangkop and FA-Platform are very similar, with a shift from higher percentages of occurrence in autumn at Slangkop to higher spring percentages at FA-Platform. An interesting change is visible in the distribution of the winter months, where the winter frequencies gradually decreases to higher frequencies in adjacent seasons (spring and autumn) percentages when moving away from Slangkop towards Richards Bay. When moving up the east coast spring and autumn events become more predominant, with even events recorded in summer at Richards Bay.

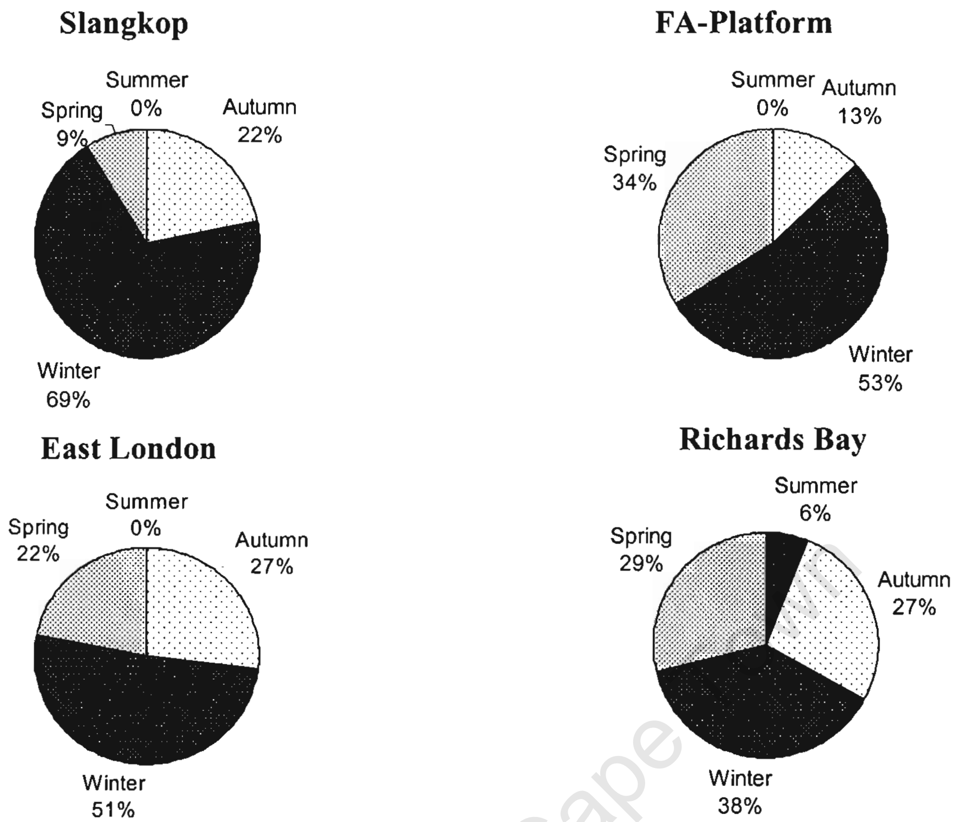


Fig 13: Distribution in percentages for the four locations and seasons

4.2.2 Significant (Hmo) and Maximum (Hmax) wave height

Wave heights between the south and east coast locations differ significantly, which was assumed when setting up the criteria to identify the events and what previous research has brought forward. In this paragraph the differences of Hmo and Hmax between locations will be further evidenced.

Table 11: Range of Significant (Hmo) and maximum (Hmax) wave height for the four locations

	Slangkop	FA-Platform	East London	Richards bay
Min Hmo (m)	6.63	6.6	4.67	4.06
Max Hmo (m)	10.8	10.7	9.3	6.44
Min Hmax (m)	11.37	12.5	8.37	7.7
Max Hmax (m)	17.09	17.9	13.79	11.35

It has to be noted that the criteria for the minimum Hmo were 6.5; 6.5; 4.5 and 4.0 for Slangkop, FA-Platform, East London and Richards Bay respectively. Differences between Slangkop and FA-Platform are relatively small. After FA-Platform wave heights decay rapidly at East London and even further at Richards Bay. The maximum Hmo of 9.3 m measured at East London is considered as an extraordinary event with a difference of 2.15 m with the following maximum Hmo.

Due to significant differences between the locations at the east coast and Slangkop/ FA-Platform it is chosen to illustrate the frequency distribution of Hmo (m) and Hmax (m) in separate figures.

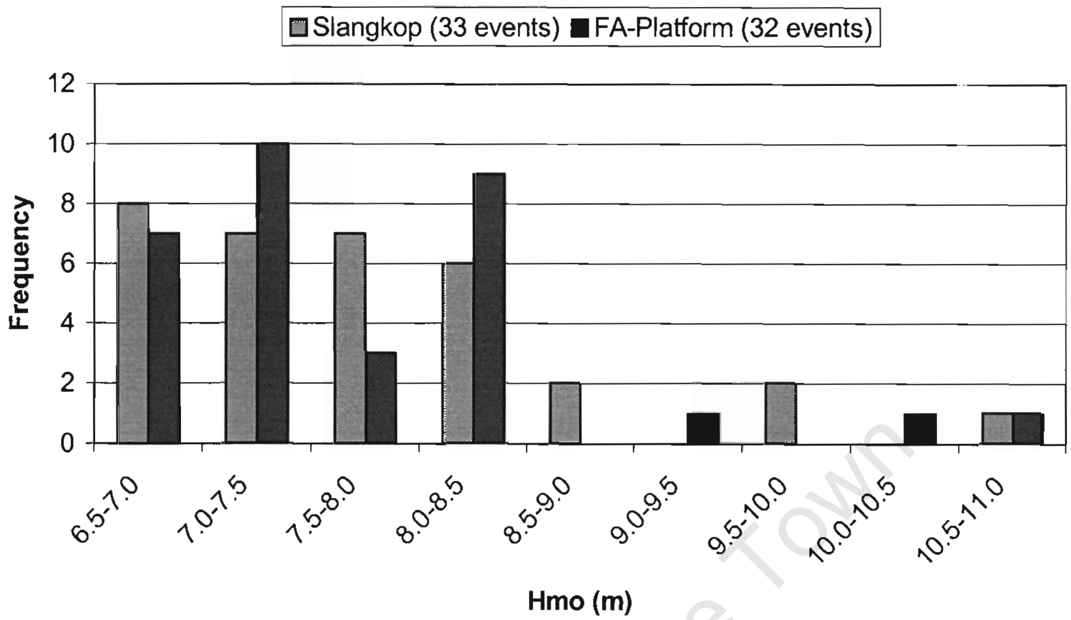


Fig 14: Distribution of significant wave height (m) for Slangkop and FA-Platform

The majority of the frequencies in Fig 14 for Slangkop and FA-Platform are situated between 6.5 m (which is the minimum value to identify an extreme wave event) and 8.5 m. Occasionally wave heights greater than 8.5 m occur.

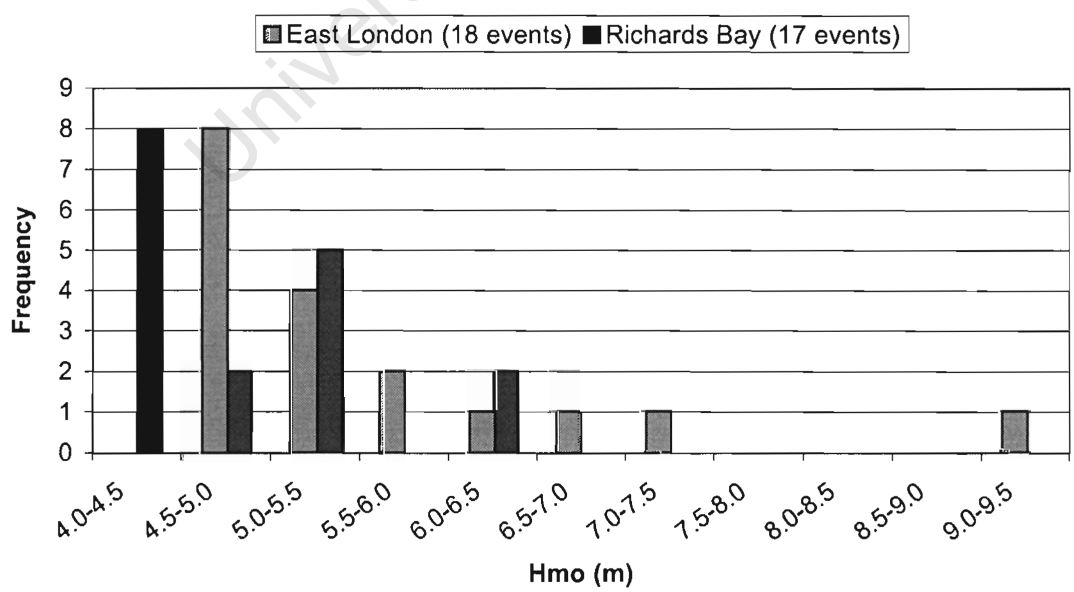


Fig 15: Distribution of significant wave height (m) for East London and Richards Bay

For East London and Richards Bay the situation is different than for Slangkop and FA-Platform. The differences between the locations are greater at the east coast with East London as the only location with frequencies greater 6.5 m. Most of the frequencies for East London and Richards Bay are confined between 4.0 m and 5.5 m, where it has to be noted that the minimum Hmo at East London to identify an extreme wave event is 4.5 m, while at Richards Bay this is 4.0 m. That is the reason no frequencies are present smaller than 4.5 m at East London.

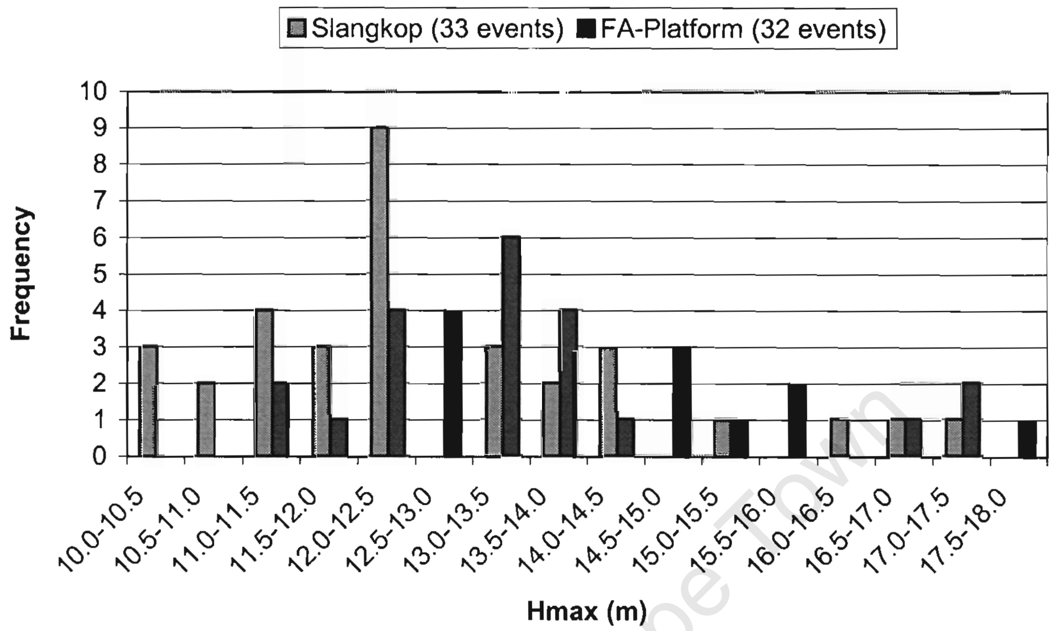


Fig 16: Distribution of maximum wave height (m) for Slangkop and FA-Platform

Frequencies of Hmax at Slangkop are mostly confined between 10.0 m and 12.5 m, while at FA-Platform these are mostly confined between 12.0 m and 14.0 m. FA-Platform is slightly more frequent in the upper range of Hmax.

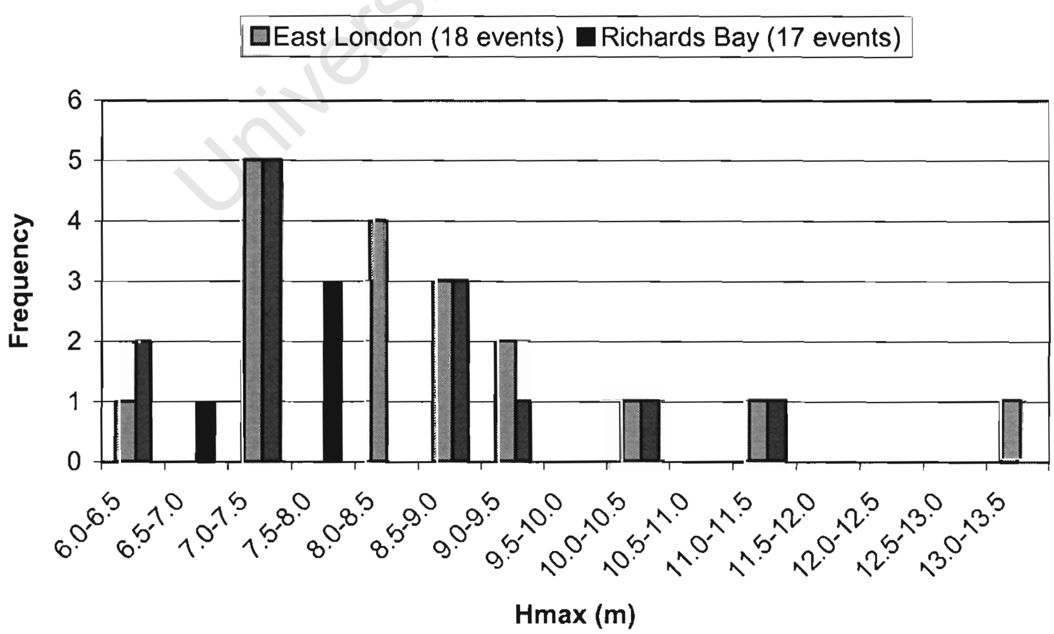


Fig 17: Distribution of maximum wave height (m) for East London and Richards Bay

Distribution of Hmax for East London and Richards Bay does not differ significantly. Only slightly higher frequencies for East London at a greater Hmax are recorded.

4.2.3 Slopes

The slopes are calculated to indicate in which rate the significant wave height (Hmo) and maximum wave height (Hmax) increases in 24 hours. The 6-hourly slope of the significant wave height (Hmo) is calculated to determine the maximum rate the wave height will increase in 6 hours. Table 12 and 13 shows average slopes and standard deviations of all events for each location.

Table 12: Average slopes and Standard deviation for each location in mhr^{-1}

Location	Hmo 24-hourly slope (smoothed)		Hmax 24-hourly slope (smoothed)		Max 6-hourly slope Hmo	
	Average	Stdev	Average	Stdev	Average	Stdev
Slangkop	0.16	0.054	0.25	0.088	0.36	0.12
FA-Platform	0.16	0.061	0.27	0.13	0.45	0.13
East London	0.12	0.037	0.16	0.065	0.33	0.16
Richards Bay	0.092	0.034	0.13	0.058	0.29	0.10

Table 13: Average slopes and standard deviation for each location in $mday^{-1}$

Location	Hmo 24-hourly slope (smoothed)		Hmax 24-hourly slope (smoothed)		Max 6-hourly slope Hmo	
	Average	Stdev	Average	Stdev	Average	Stdev
Slangkop	3.94	1.31	6.02	2.12	8.59	2.89
FA-Platform	3.94	1.47	6.42	3.06	10.82	3.20
East London	2.83	0.89	3.57	1.56	8.00	3.76
Richards Bay	2.21	0.83	3.14	1.39	6.97	2.49

The 24-hourly slopes are identical between Slangkop and FA-Platform. This means that the significant wave height will increase on average almost 4 m in 24 hours for these two locations. After FA-Platform Hmo decreases rapidly (average 1.11 $mday^{-1}$) towards East London. Towards Richards Bay Hmo is still decreasing, but less fast with an average of 0.62 $mday^{-1}$.

4.2.4 Duration

The average duration of each event for each location is determined by looking at the time significant wave heights exceeded 6.0 m at Slangkop and FA-Platform, 4.5 m at East London and 4.0 m at Richards Bay.

It has to be noted that event 3 at Richards Bay is classified as an extraordinary event with as its duration was 102 hours. The duration is in such an excess of the other events that this event is left out to calculate the mean duration for Richards Bay.

Table 14: Average duration and Standard deviation for each location

Location	Duration (hours)	
	Average	Stdev
Slangkop	18	9.2
FA-Platform	16	10.2
East London	12	11.1
Richards Bay	7.5	4.81

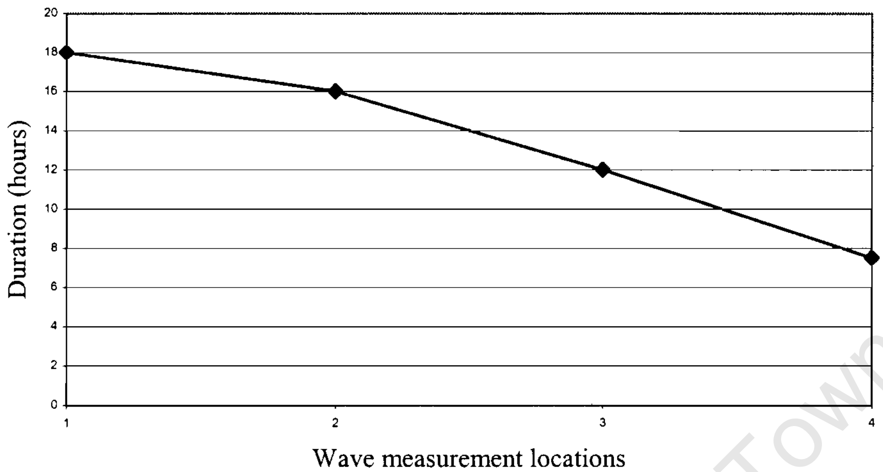


Fig 18: Relationship between average durations and locations

The average duration at Slangkop is slightly longer than FA-Platform, with a difference of 2 hours. After FA-Platform a linear relationship is present (See Fig 18) when moving further up the east coast towards Richards Bay where the duration is 71/2 hours and almost twice as short as FA-Platform.

4.2.5 Maximum Hmo and Hmax

Table 15: Average Hmo (m) and standard deviation at the peak of each event for the four locations

Location	Max Hmo (m)	
	Average	Stdev
Slangkop	7.72	1.01
FA-Platform	7.70	0.94
East London	5.53	1.19
Richards Bay	4.78	0.72

Table 16: Average maximums of Hmax and Standard deviation at each location

Location	Hmax max (m)	
	Average	Stdev
Slangkop	12.66	1.8
FA-Platform	13.44	1.79
East London	8.66	1.73
Richards Bay	7.98	1.42

The maximum Hmax at Slangkop is a bit lower than FA-Platform, while after FA-Platform significant changes occur till East London. The difference between East London and Richards Bay is less pronounced than between FA-Platform and East London.

4.2.6 Period versus Direction plots

It is assumed that swells of a certain period mostly come from one direction. This is the reason why analysis was done on the direction versus peak periods for Slangkop, East London and Richards Bay. FA-Platform does not measure wave directions. One of the reasons to look at the direction as well is to identify differences between the dominant south westerly swells or south easterly swell that can cause significant damage to coastal structures (See § 6.4 Impacts of extreme wave events).

A) Peak periods (Tp)

Wave periods can tell a great deal of information about the energy and source of the swells. At FA-Platform peak periods (Tp) are not measured but the peak energy period or the average zero crossing period (Tz). This is therefore not included in this paragraph.

Table 17: Mean peak periods (Tp) during each event and during peak of events

Location	Full event	During peak
	Mean Tp (s)	
Slangkop	12.9	15.4
East London	12.8	13.7
Richards Bay	11.6	12.7

It has to be noted that periods are recorded in discrete frequencies. Therefore exactly the same periods are measured during different events. For example at Slangkop during 19 events a period of 15.52 seconds was measured during the peak of each event.

Table 20: The longest peak wave periods with associated significant wave height (the data for Agulhas Bank and Port Nolloth is extracted from Rossouw & Rossouw, 1999)

Station	Tp (s)	Associated Hmo (m)
Slangkop	20	9.99
Agulhas Bank	18.3	8.7
Port Nolloth	22.3	5.0
East London	18.3	5.24
Richards Bay	16	4.32

The lowest periods recorded during the events were 4.97, 4.92, and 4.53 for Slangkop, East London and Richards Bay respectively. These low periods mostly occurred just before the significant wave height increases and are due to local wind fields.

B) Directions

Slangkop:
Since 2000, Slangkop started recording directional wave measurements. In Appendix VI all directions versus peak periods plots are included.

Most plots in Appendix VI have a predominant swell direction from the south west. During some events the wave direction is a bit more scattered than during other events, but generally during the peak and when wave heights decay the swell direction lies between 210° and 250° degrees with periods between 10 and 16 seconds. The measured range lies between 199° and 336°.

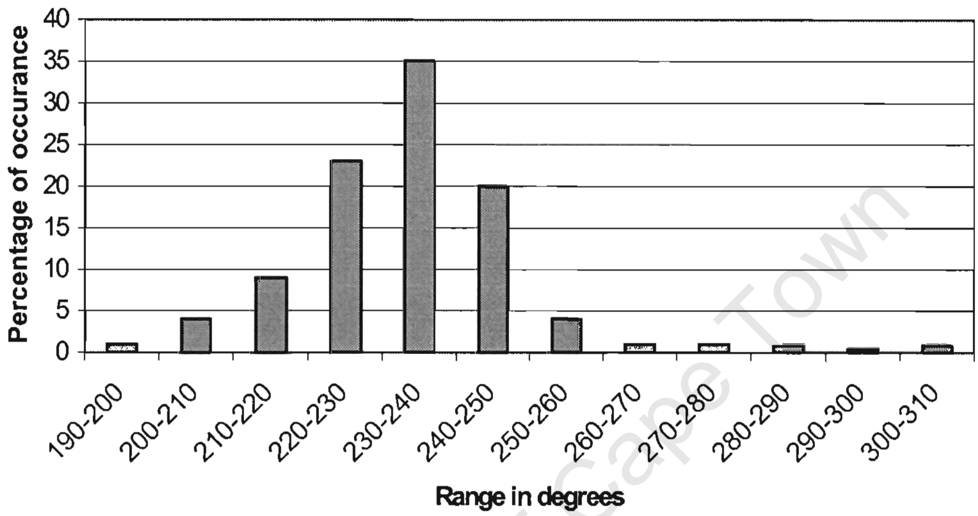


Fig 19: Directional distribution for Slangkop in percentages for the events since 2000

Fig 19 shows a very pronounced peak between 230° and 240° degrees, with a wave/ swell direction between 220°-250° degrees for almost 80% of the time.

East London:
Directional wave measurements started in 2001 at East London with 4 identified event after this date, which are presented in Appendix VI. The swell direction during the events since 2001 have a much wider band than at Slangkop. Most swells are mainly coming from 170° to 190° degrees, with a measured range between 62° and 224° (See Fig 20). Peak periods are mainly situated between 8 and 16 seconds.

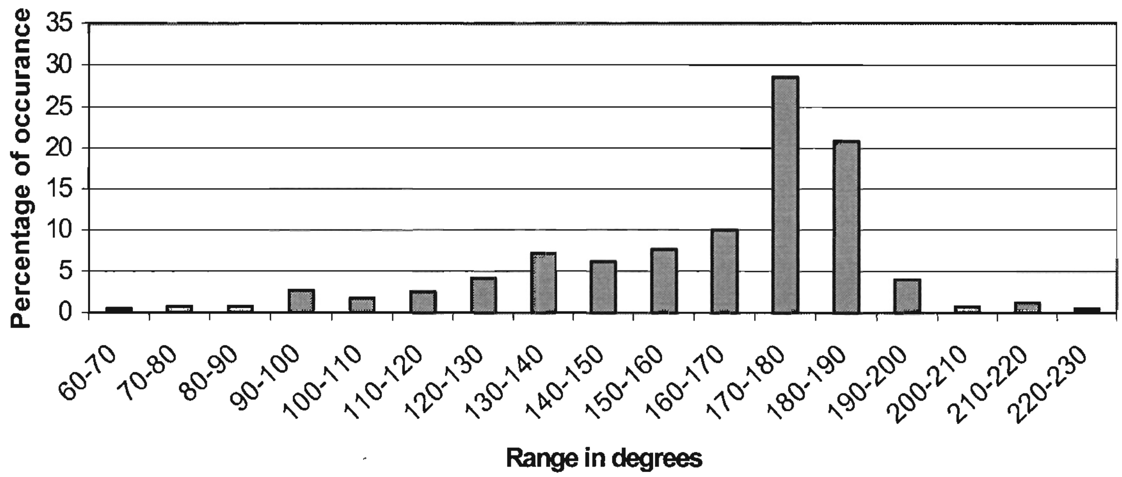


Fig 20: Directional distribution for East London in percentages for the events since 2001

Richards Bay:

Directional measurements at Richards Bay were initiated in 2000 with six identified events after this date, which are presented in Appendix VI. The wave directions at Richards Bay are much more scattered than at the other three locations, with a small majority of events between 150° and 160° degrees (See Fig 21). The direction ranges between 69° and 200° degrees, with the majority of waves/ swell coming from a direction between 100° and 170° degrees.

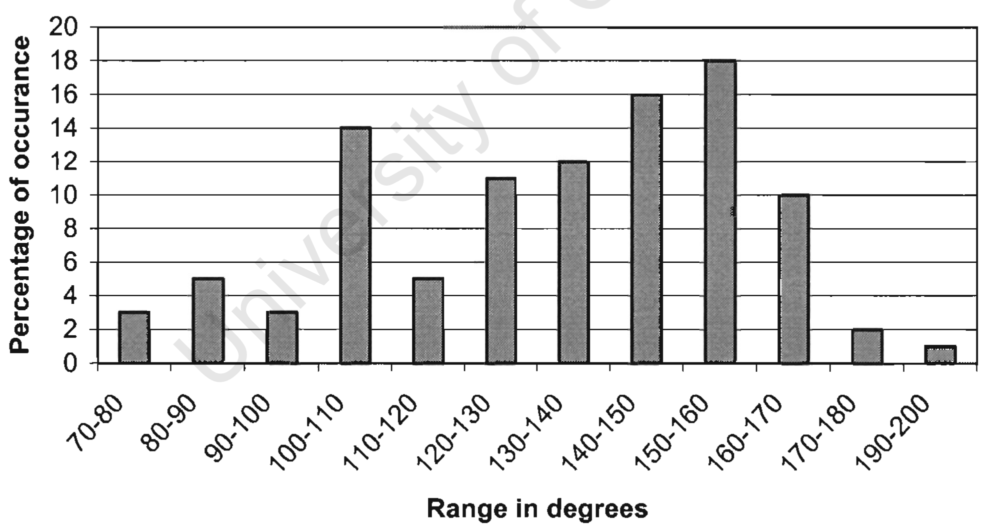


Fig 21: Directional distribution for Richards Bay in percentages for the events since 2001

4.2.7 Energy

This so called radiation stress or momentum flux is calculated to see what kind of forces offshore structures like oil-platforms in the deep ocean have to withstand during an event. The radiation stress is calculated for all four "deep water" locations and will only be an indication what the radition stress will be closer to the shore, due to the change in wave characteristics. No information is available of Hmo in shallow water and can only be guessed. Therefore only deep-water recordings will be inserted in the following equation.

Radiation stress $T_{XX} = \bar{E} \cdot (2 \cdot \text{group } c / c - \frac{1}{2})$
$= \frac{1}{2} \cdot \bar{E}$

Its units are $Jm^{-2} = Nm^{-1}$, which is the force per crest length

And with;

$\bar{E} = 1/16 \cdot \rho \cdot g \cdot Hmo^2$

As an example the radiation stress is calculated for a Hmo of 6.0 m (identical Hmo used for calculating the duration of an event at Slangkop) and the maximum is 10 m (9.99 m).

Radiation stress $T_{XX} = \frac{1}{2} \cdot 1/16 \cdot 1000 \cdot 9.8 \cdot 6^2$
$= 11025\ Nm^{-1}$

The remainder of the calculations of minimum and maximum Hmo and Hmax for the four locations are presented in Table 19.

Table 19: Radiation fluxes (Nm^{-1}) in Italic for the minimum and maximum Hmo (m) and Hmax (m) for the four locations

	Hmo (m)		**Hmax (m)**	
	Min	**Max**	**Min**	**Max**
Slangkop	6.0	10.8	11.37	17.09
	11,025	*35,721*	*39,591*	*89,446*
FA-Platform	6.0	10.7	12.5	17.9
	11,025	*35,063*	*47,852*	*98,126*
East London	4.5	9.3	8.37	13.79
	6,202	*26,488*	*21,455*	*58,238*
Richards Bay	4.0	6.44	7.7	11.35
	4,900	*12,701*	*18,158*	*39,452*

Due to the fact that the wave height is squared in the equation used, very pronounced differences exist between the radiation stress for different wave heights.

4.3 Correlated events

FA-Platform wave measurements commenced in 1996. Since this year 32 events were identified for FA-Platform. Since 1996, 14 events were identified for Slangkop. Of those 14 events 13 events correlate with FA-Platform (is the same event). So there is a 93% chance that when an event occurs at Slangkop, it will also occur at FA-Platform. There is an excess at FA-Platform of 19 events compared to Slangkop, which means that there are 60% more events occurring at FA-Platform compared to Slangkop.

Analyses is undertaken for the 13 correlated events at Slangkop and FA-Platform looking at different parameters. The following results were determined:

- There is an average time difference of 4.08 hours between the peak of each event, when an event occurs at Slangkop it will arrive approximately 4 hours later at FA-Platform.
- The average Hmo at the peak is 0.04 m higher at Slangkop.
- The average maximum Hmax at FA-Platform is 1.06 m higher.
- The average 24-hour Hmo slope is exactly the same.
- At FA-Platform the average 24-hour Hmax slope is 2.33 $mday^{-1}$ bigger.
- At FA-Platform the average maximum 6-hour Hmo slope is 0.72 mhr^{-1} bigger.
- The duration at Slangkop is 41 min longer.

According to those figures the differences between the characteristics during the correlated events are minimal. Only the Hmax can be expected to be approximately a meter bigger at FA-Platform and the average 24-hourly Hmax slope and average maximum 6-hourly slope increases significantly faster than at Slangkop.

Correlation between FA-Platform and East London is relatively inaccurate, because only four events correlate to each other:

- The average time difference when an event passes FA-Platform and arrives at East London is 39 hours and 15 min.
- The average Hmo at the peak of an event is 2.9 m bigger at FA-Platform.
- The average maximum Hmax at FA-Platform is 6.1 m bigger.
- At FA-Platform the average 24-hour Hmo slope is 0.79 $mday^{-1}$ bigger.
- At FA-Platform the average 24-hour Hmax slope is 2.18 $mday^{-1}$ bigger.
- At FA-Platform the average maximum 6-hour Hmo slope is 0.83 mhr^{-1} bigger.
- The duration at FA-Platform is 11.5 hours (11 hours and 30 min) longer.

Three events correlate with each other at East London and Richards Bay:

- The event will arrive another 49 hours later at Richards Bay than at East London.
- At East London the average Hmo is 0.45 m bigger.
- The duration at Richards Bay is 1.33 hours (1 hour and 20 min) longer.
- The 24-hourly slopes at East London are a bit steeper with Hmo 0.77 $mday^{-1}$ and Hmax 1.09 $mday^{-1}$.
- The average maximum 6-hourly slope is approximately the same.
- The average maximum Hmax is 1.13 m bigger than at East London.

It has to be noted that none of the events that were identified at FA-Platform coincided with an event at Richards Bay. Therefore it is assumed that different weather patterns are responsible for the extreme wave events at Richards Bay compared to FA-Platform. It also have to be emphasised that FA-Platform only started operating in 1996, but still no similar dates between Slangkop and Richard Bay before 1996 are present.

There are only two events that occurred at Slangkop, FA-Platform and East London at the same time. The first was in June 1992 (Slangkop event 16 and East London event 1), but FA-Platform was not operational yet. Slangkop event 20, FA-Platform event 1 and East London event 9 could be a correlated event for all three locations but. After analysing the synoptic weather charts it became clear that two different cold fronts are responsible for the extreme wave events and therefore no comparison could be made.

4.4 Differences between locations

A general comparison of the main characteristics (Hmo, Hmax and Tp) between the different locations is undertaken to identify main differences. The results in this chapter show that at the east coast the significant and maximum wave heights and the slopes decrease compared to Slangkop and FA-Platform. Analysing the graphs in Appendix II to V it become further evident that the events at Slangkop and FA-Platform have a much stronger evolvement to a peak and faster decay after the peak duration.

In some cases at East London and Richards Bay, the same characteristics apply, but it seems that the evolvement to the peak is much more gradual and that there isn't a pronounced peak as for the other two locations. This is due to the rapid decay of wave heights from south to east coast and also due to that at the east coast not only the cold fronts are responsible for the extreme wave events but also other local weaker weather patterns (See § 5.1, Correlation of weather patterns and identified events).

Peak period patterns are quite similar between locations. Only at the east coast the mean period is a bit smaller than at Slangkop. It also seems that that the periods differ more (more spikes) compared to Slangkop.

Chapter 5: Weather patterns responsible

The wave climate along the South African coast is determined by the wind patterns blowing over the oceans. For extreme wave events these wind patterns have to be either strong, blow over a considerable fetch or considerable duration. It is stated by Harris (1972) that the extreme wave climate is mostly due to specific atmospheric conditions on the oceans surrounding the coast of South Africa. It is not possible to discuss the extreme wave climate alone without paying attention to the weather types responsible for these extreme wave events.

In the following paragraphs the atmospheric conditions responsible for South Africa's extreme wave climate are discussed. Different parameters like the; intensity, velocity and tracks are discussed as well as an estimation of swell directions by analysing the isobars in the daily weather bulletins.

5.1 Correlation of weather patterns and identified events

The daily weather bulletins issued by SAWS (South African Weather Service) were analysed to identify the weather patterns responsible for the extreme wave events along the South African coast.

Table 20: Identified atmospheric conditions responsible for extreme wave events

Event no.	**Slangkop**	**FA-Platform**	**East London**	**Richards Bay**
1	Cold front	Cold front	Cold front	Tropical cyclone
2	Cold front	Cold front	Cold front	Cold front
3	Cyclogenesis	Cold front	Cold front	Cut-off low
4	Cold front	Explosive cyclogenesis	Cold front	Coastal low
5	Explosive cyclogenesis	Explosive cyclogenesis	Cut-off low	Cold front
6	Cold front	Cold front	Cold front	Cold front
7	Cold front	Cold front	Cut-off low	Cold front
8	Cold front	Cold front	Cold front	Cold front
9	Cold front	Cold front	Cold front	Cut-off low
10	Cold front	Cyclogenesis	Cold front	Cold front
11	Explosive cyclogenesis	Cold front	Cold front	Cold front
12	Cold front	Cold front	Cold front	Cut-off low
13	Cold front	Cold front	Cut-off low	Cold front
14	Cyclogenesis	Cyclogenesis	Cold front	Cut-off low
15	Cold front	Cold front	Cold front	Cold front
16	Cold front	Cyclogenesis	Coastal low	Cut-off low
17	Cold front	Cold front	Cold front	Cut-off low
18	Explosive cyclogenesis	Cold front	Cold front	
19	Cyclogenesis	Cyclogenesis		
20	Cold front	Cold front		
21	Cold front	Cold front		
22	Explosive cyclogenesis	Cut-off low		
23	Explosive cyclogenesis	Cold front		
24	Cyclogenesis	Cyclogenesis		
25	Cold front	Cold front		
26	Cyclogensis	Cyclogenesis		

27	Cold front	Cold front
28	Cut-off low	Cyclogenesis
29	Cyclogenesis	Cold front
30	Cold front	Explosive cyclogenesis
31	Cyclogenesis	Cold front
32	Cold front	Cold front
33	Cold front	

Table 21: Distribution of atmospheric conditions responsible for extreme wave events in absolutes and percentages.

	Slangkop	**FA-Platform**	**East London**	**Richards Bay**
Tropical cyclone	0	0	0	1 (6%)
Cold front	20 (61%)	21 (66%)	14 (78%)	9 (53%)
Coastal low	0	0	1 (5%)	1 (6%)
Cut-off low	1 (3%)	1 (3%)	3 (17%)	6 (35%)
Cyclogenesis	7 (21%)	7 (22%)	0	0
Explosive cyclogenesis	5 (15%)	3 (9%)	0	0

The vast majority responsible for the identified extreme wave events along the South African coast are cold fronts. Especially at Slangkop, FA-Platform and East London almost ¾ of the extreme wave events are caused by cold fronts., almost 100% of all extreme wave events at Slangkop and FA-Platform are caused by cold fronts, when considering (explosive) cyclogenesis as a cold front too. One cut-off low was identified for Slangkop and FA-Platfrom. It has to be noted that in this thesis a cold front in its generation phase that has a center drop of 20 mb in 24 hours is referred to as an explosive cyclogenesis. During cyclogenesis the center pressure only drops 4-10 mb in 24 hours.

Moving up the east coast other weather types like tropical cyclones, coastal lows and cut-off lows are responsible for some events. For Richards Bay a less obvious pattern exists than for the southern Cape. At Richards Bay cut-off lows are getting more frequent, together with coastal lows in a lesser extent. Even tropical cyclones have to be taken into account for the KwaZulu-Natal coast. Weather patterns responsible for events at the east coast can be identified at East London as a cold front but could be responsible for the event at Richards Bay as a cut-off low.

Table 22: Seasonal distribution of weather patterns responsible for extreme wave events along the SA coast.

	Summer	**Autumn**	**Winter**	**Spring**
	Dec-Jan-Feb	**March-April-May**	**June-July-Aug**	**Sept-Oct-Nov**
Tropical cyclone	1	0	0	0
Cold front	0	10	36	18
Coastal low	0	0	0	2
Cut-off low	0	2	5	4
Cyclogenesis	0	4	10	0
Explosive cyclogenesis	0	2	5	1

5.2 Velocity of weather patterns

The propagation velocity of cold fronts during extreme wave events identified at Slangkop and FA-Platform is approximately 48.4 $kmhr^{-1}$ an hour, which is 8 $kmhr^{-1}$ faster than the average velocity estimated by Van Loon (1967) for cold fronts in winter. Estimated velocities of cold fronts range between 14.2 $kmhr^{-1}$ and 84.3 $kmhr^{-1}$ an hour.

The weather patterns responsible for extreme events at Richards Bay tend to be much slower moving than the cold fronts of the Southern Cape, especially when bud off highs trap cut-off lows or when a coastal low is trapped between the interior and Madagascar. In some cases, coastal lows and cut-off lows tend to be very slow moving with estimated velocities of 18 $kmhr^{-1}$ or sometimes even less.

5.3 Intensity of weather patterns

Intensities of the center pressure form an important factor to determine how developed a cold front or depression is. A cold front with a center pressure of 960 mb at the same location as a cold front with center pressure 980 mb, is more likely to be associated with stronger winds. Therefore distribution tables will show some pronounced differences between locations and especially when rounding the south coast towards East London.

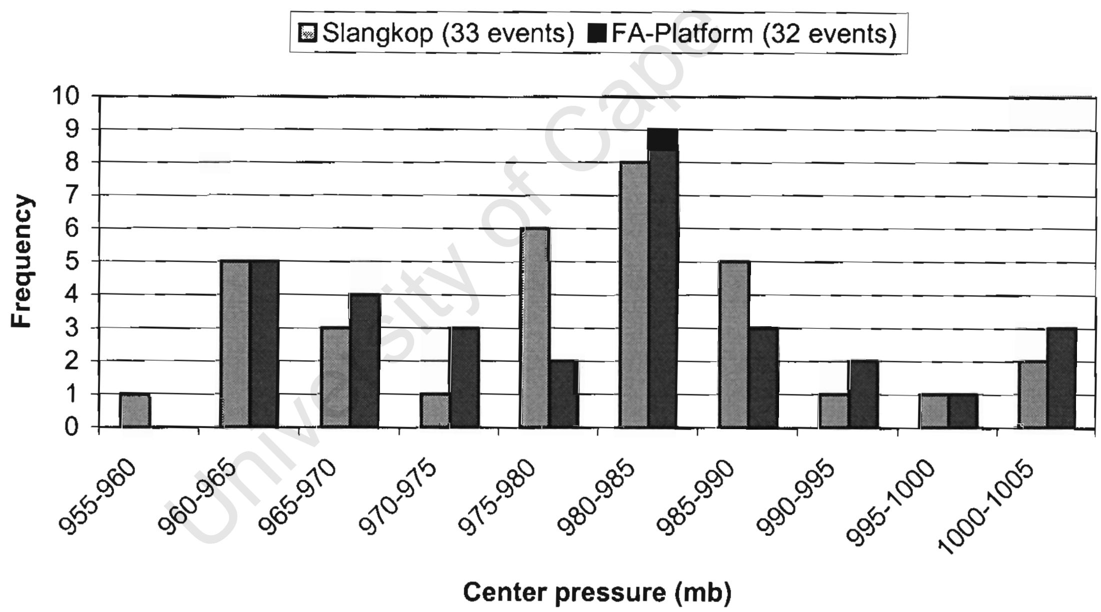


Fig 22: Frequency distribution of center pressures (mb) at Slangkop and FA-Platform

Center pressures of explosive cyclogenesis are included in Fig 22 and they form a significant percentage of the most intense cold fronts as can been seen in Table 23.

Table 23: Center pressures (mb) of identified explosive cyclogenesis for Slangkop and FA-Platform.

Slangkop		FA-Platform	
Event	**Center pressure (mb)**	**Event**	**Center pressure (mb)**
5	960	4	960
11	958	5	960
18	976	30	980
22	960		
23	968		

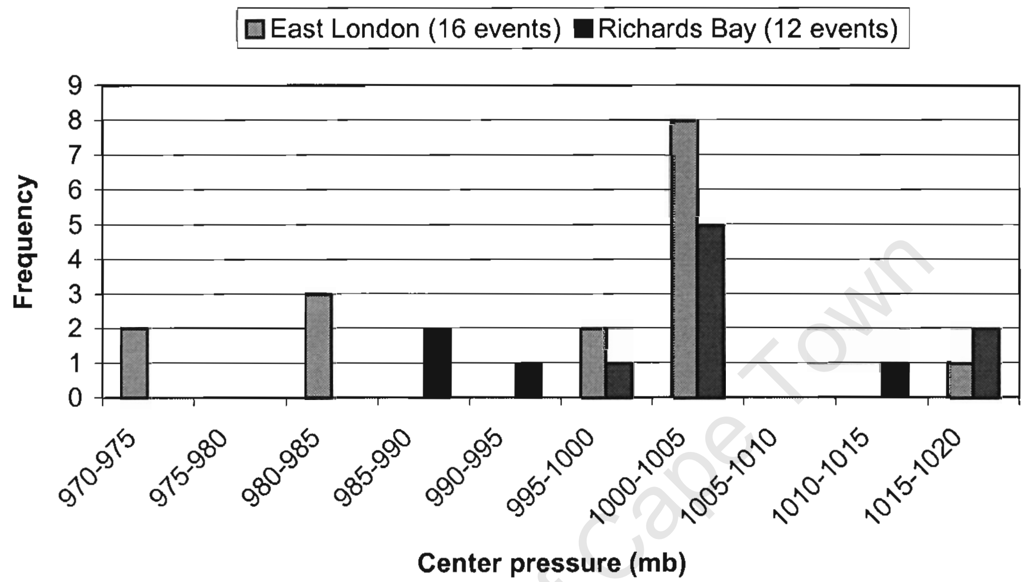


Fig 23: Frequency distribution of the center pressures (mb) at East London and Richards Bay.

In Fig 23, cut-off lows are not included, because sea level pressures can be caused by high pressure systems and in some cases the cut-off low only exist above the interior or in the upper air. Coastal lows and tropical cyclones are included.

5.4 Track of weather patterns

Tracks of weather patterns (cold fronts) responsible for extreme wave events at Slangkop mostly propagate in an eastward direction. A fair quantity (approx. 30%) of cold fronts travel in a more east south eastward direction. In some cases the cold fronts that come from a latitude of 40° S or further south propagate in an east north easterly direction.

The tracks of cold fronts and (explosive) cyclogenesis are very straightforward on the Agulhas Bank. The vast majority travel in an eastward direction. Only a relative small percentage (approx. 10-15 %) will travel a more east south easterly direction and in some cases the propagation of cold fronts is east north easterly.

Cold fronts at East London are propagating mostly eastward, but significant numbers propagate to the north east. Cut-off lows can stay in approximately the same position for several days before they slowly dissipate.

At Richards Bay the coastal lows mostly propagate to the north east, while tropical cyclones will propagate to the south west. Cut-off lows propagate in an array from north west to south east. Cold fronts mostly travel to an easterly or east north easterly direction. It has to be noted that in some cases coastal lows or cut-off lows stay at approximately the same location.

5.5 Estimated swell directions

Before directional wave measurements at Slangkop, East London and Richards Bay started the wave directions are estimated by interpreting isobars on the daily weather bulletins during the identified events. At FA-Platform wave directions are estimated since 1996.

Estimated wave directions for Slangkop are in good agreement with the measured wave directions since 2000. Around 70% of the waves comes from a south westerly direction. Around 17% comes from the west south west, while the remainder comes from or north westerly or southerly directions.

At FA-Platform the majority of events have a south westerly direction with approximately 54%. At the Agulhas Bank swell directions have a bit more a westerly component seen by 29% coming from the west southwest and 13% coming from the west. Only 3% comes from the south south west and only one 1% has a west north westerly direction.

The directional pattern at East London is much more variable compared to Slangkop and FA-Platform. A significant quantity of the events have a more easterly or south easterly swell direction. Around 55% comes from a direction with an easterly component, with mostly south easterly swells. The extraordinary event at East London in June 1997, with a significant wave height of 9.3 m, came from the south east. The rest of the swells come mostly from the south, which is in good agreement with the measured directions since 2001.

At Richards Bay most of the swells come from an easterly direction, with highest counts of south easterly components. Some swells come from a more southerly direction and even cut-off lows or coastal lows can initiate swell from the east or north east.

Chapter 6: Discussion and conclusions

In this chapter all the results are interpreted and put into context. This chapter will

- Answer the key question, is it getting stormier along the coast off South Africa?
- And will introduce impacts of extreme wave events on shipping and coastal developments.

Finally, further possibilities of research about this topic will be outlined.

First all the main results will be concluded together with reasons why similarities and differences between locations along the coast are present. It has to be emphasised that no identified extreme wave event is identical to another. Therefore forecasting of exact wave heights and event characteristics is a difficult task. For this reason averages were calculated to give a good indication of what the mean expectations would be during an extreme wave event.

As explained in § 2.2, South African wave climate, the wave climate is referred to as a "high wave climate". In this dissertation only events are researched that are the most intense storms, which are responsible for the highest waves recorded along the South African coastline. A total of 100 events were identified for Slangkop (33 events), FA-Platform (32 events), East London (18 events) and Richards Bay (17 events). The quantities differ from each other, because of different operation times of the recording instrumentation or due to the set up criteria according to the design wave heights from Rossouw 1989.

6.1 Extreme wave event characteristics

When researching the distribution of events for the different months or seasons it can be concluded that winter is the far most predominant season where extreme wave events occur. Especially at Slangkop where 69% of the events occurred in the winter months (June, July, Aug). At FA-Platform and East London around 50% of the events occured in winter, while at Richards Bay only 38% of the events occured in winter. At FA-Platform a distinctive shift between spring (34%) and autumn (13%) is evident, while at Slangkop more events were identified in autumn (22%) compared to spring (9%). There is a very obvious shift in the distribution of events when rounding the south coast towards East London. More events were identified in spring and autumn for East London and this pattern proceeds towards Richards Bay where even events in the summer were identified. Therefore it can be concluded that when moving up the east coast different weather patterns, that occur in different seasons, are responsible for the extreme wave events, which will be discussed in the latter of this chapter.

Previous research, by Rossouw J. (1989) and Rossouw M. (2001), showed that the general wave climate differ along the coast off South Africa. It can be concluded that this is also the case during extreme wave events. All extreme wave event measurements, since the deployment of the CSIR wave-recording network around the coastline, verify this conclusion. The highest maximum wave heights (Hmax) recorded on the coastline were 17.1 m at Slangkop, 17.9 m at FA-Platfrom, 13.8 m at East London and 11.35 m at Richards Bay. In the same order the highest significant wave heights (Hmo) recorded at these locations were 10.8 m, 10.7 m, 9.3 m and 6.44 m.

What are the wave heights that can expected during an event? This is an extremely difficult question and cannot be answered by such a small dataset. However it can be indicated what at the average expectations are during an event. Paragraph 4.2.5 Maximum Hmo and Hmax, conclude the following average situation along the South African coast can be expected.

Table 24: Average Hmo and Hmax at the peak of each event

Location	**Wave heights (m)**	
	Hmo	**Hmax**
Slangkop	7.72	12.66
FA-Platform	7.70	13.44
East London	5.53	8.66
Richards Bay	4.78	7.98

Table 24 is in good agreement with Rossouw (1989) that wave heights are very similar at the south coast and diminishes significantly when rounding the south coast to the east.

In general, the majority of identified events at Slangkop and FA-Platform have a Hmo range between 6.5 and 8.5 m. Waves recorded in excess of 8.5 m are considered to be extraordinary events changes of Hmo greater than 8.5 m at Slangkop or FA-Platform is approximately 12%.

Comparing the maximum measured Hmo of 10.8 m at Slangkop with the 100-year design wave height according to Rossouw & Rossouw (1999) of 11.6 m indicates that a possibility exists that an event might occur with a Hmo that is never recorded yet in South African waters. The once in 10-year returning period at Slangkop with a Hmo of approximately 9.4 m according to Rossouw (1989) is in good agreement with three recorded events having wave heights greater than 9.37 m for a dataset of 25 years.

At East London and Richards Bay the majority of identified events range between a Hmo of 4.0 and 5.5 m, with a change of Hmo's greater than 5.5 m of approximately 23%. It has to be noted that in East London only events were analysed with a Hmo greater than 4.5 m, due to the set up criteria.

Hmax measurements during the identified events show a similar pattern as for Hmo. Only frequencies of Hmax at the Agulhas Bank are greater (12.0 to 14.0 m) than at Slangkop (10.0 to 12.5), which is due probably due to the difference in depth between the two measuring sites and due to the location. FA-Platfrom is measuring at the Agulhas Bank, which is more exposed to the general pattern of cold fronts. This will be further discussed in this chapter.

Frequencies of Hmax at East London and Richards Bay are mostly confined between 7.0 and 9.5 m, which verifies that very pronounced differences exists between the two locations situated at the south coast compared to the locations at the east coast. Especially between FA-Platform and East London drastic reduction in wave heights occurs, which is also concluded by Rossouw in 1989.

When looking at the average rate of which the wave height increases during events (refer to § 4.2.3 Slopes), it will be evident that similar patterns exist, as with the decreasing of wave heights, when rounding the south and moving up the east coast. When interpreting the average slopes in $mday^{-1}$ it becomes evident that over a day the wave height prior to the peak, increases with a maximum of 3.94 m. When the initial state of the sea prior to an event for the south coast is e.g. 2 m, the wave height has to increase longer than a day to reach its peak, which has to be greater than 6.5 m to be identified as an event for the south coast. When comparing slopes for Slangkop and FA-Platform, the smoothed 24-hourly Hmo slope is identical with an increase of wave height of 3.94 $mday^{-1}$. Comparing the smoothed 24-hourly Hmax slope, FA-Platform will see a faster increase of Hmax of 0.4 $mday^{-1}$ (also greater Hmax compared to Slangkop as discussed previously). An important conclusion for shipping is that the average maximum 6-hourly Hmo at FA-Platform slope increases 0.45 mhr^{-1}, with maximums of almost 3.5 m of Hmo in 6 hours. This rate is a bit smaller at Slangkop (0.36 mhr^{-1}). Towards East London the 24-hourly Hmo slope decreases with 1.11 $mday^{-1}$ compared to FA-Platform and from East London towards Richards Bay it decreases with another 0.62 $mday^{-1}$. 24-hourly Hmax slopes decrease almost 3 $mday^{-1}$ when rounding the south coast.

The longest average duration of events is identified at Slangkop (18 hours) and is comparable to FA-Platform (16 hours). The duration of an event at the east coast is much shorter, which again has to do with the change of weather patterns responsible for the events and due to less exposure to the depressions compared to the south coast. The high standard deviation is normal for calculating durations as was experienced previously by M Rossouw.

Peak periods (Tp in s) show a similar pattern as found for wave heights, slopes and duration. During the peak of events at Slangkop the average Tp is 15.4 s, which is evidence of mostly long distance swell, originated from a long fetch and consistent strong wind velocities from a south westerly direction, which is in agreement with the predominant swell directions measured at Slangkop

At East London Tp decreased to 13.7 s, which is an indication that the swell originated closer to the measurement location. This becomes further evident when looking at the weather patterns responsible for the events. Directional measurements show a majority of the swell coming from a south southwesterly till a south easterly direction.

At Richards Bay Tp decreased even more till 12.7 s and indicate an even more bi-modal character of the wave climate due to swells and wind waves. This is because weather patterns responsible for the events differentiate from the cold fronts responsible at the south coast. The weather pattern responsible tend to be closer to the coast such as the cut-off low and coastal low which produce higher-frequency waves.

As discussed previously, during some events Tp drops significantly just before or during the initiation of an extreme wave event. At Slangkop this occurred during event 28, 31, 32 and 33 (Refer to Appendix II). During each of these events the swell direction also changed from south west to mainly north west (in one case even almost north). This is due to the wind patterns associated with the passing of a cold front that cause strong north westerly winds (See § 2.3.1, cold fronts). These winds cause locally developed shorter period wind chop with periods between 6 and 10 seconds. These changes in swell direction are relatively short and only last for maximal 6 to 9 hours before the swell direction changes to a more westerly component and finally changes to a south westerly direction.

At East London and Richards Bay the same situation occurs during a few cases. The swell direction suddenly changes to another component with periods lower than 8 seconds. This is probably due to the presence of a strong south westerly or a strong north easterly wind.

It can be concluded that there is a strong correlation between Slangkop and FA-Platform. When an event occurs at Slangkop there is a 93% change the same event will occur at FA-Platform, with an average lack of approximately 4 hours at the peak of an event. Almost all characteristics of the correlated events were similar, where man can expect: the exact same Hmo, 1 m higher Hmax of at FA-Platform, same 24-hourly Hmo slope, slightly higher 24-hourly Hmax and maximum 6-hourly Hmo slope at FA-Platform, a longer duration of 41 minutes at Slangkop.

The differences between the correlated events are due to differences in measuring depth of the wave recording instrumentation and the more exposed location of FA-Platform to the general track of cold fronts.

Due to its more exposed location approximately 60% more events occur at FA-Platform than at Slangkop.

The estimated passage of time between events at FA-Platform and East London is around 40 hours and between East London and Richards Bay around 49 hours. These estimates could be inaccurate due to the small amount of correlated events.

In general wave characteristics as analysed for all the identified events form good agreement with previous work undertaken by Rossouw J. (1989), van der Westhuyzen (2002) and Rossouw M. (2001) who also concluded that after Port Elizabeth (between FA-Platform and East London) wave heights diminish rapidly. When moving further up the east coast wave heights will slowly diminish together with the other event characteristics (Tp, duration, slopes).

What are the reasons for this rapid diminishment of wave heights?

1) Firstly the topography of the coastline where the waves have to round the African continent, which causes wave refraction and therefore loss of energy.
2) Secondly the strong Agulhas current might have an effect on the extreme wave events, this however has to be researched by deploying a wave recording buoy inshore of the current, one in the current and one on the ocean side of the current, which can also benefit research on rogue waves.
3) FA-Platform is measuring in a waterdepth of 113 m, while East London only measures in a waterdepth of 20 m, which will have an influence on the characteristics of waves, because is lost by bottom interaction and refraction.
4) Cold fronts which are responsible for the extreme events on the Agulhas Bank might be in a dissipation phase when coming to East London or get deflected by the Indian high pressure system.

5) The distance between the cold fronts and East London increases. This means the swell have to travel a longer distance and is more likely to lose energy.
6) Another reason for different wave characteristics is that other weather patterns getting more important for the generation of extreme waves.

On the other hand the extreme wave climate on the Agulhas Bank (FA-Platform) compared to the south west coast (Slangkop) is very similar as discussed previously. What are the reasons for these similarities?

1) The same weather patterns are responsible for the extreme wave events
2) They are almost located at the same latitude (34° south)
3) They are both exposed to the predominant south westerly events.

While most of the wave characteristics are identical or similar, differences are still present due to:

1) Minor differences in readings due to differences in waterdepth, Slangkop is located in 70 m (which has a slight influence on the readings) while FA-Platform is located in a waterdepth of 113 m, especially with the highest waves with long wave lengths will interact with the bottom and cause a change of wave characteristics.
2) Even that the latitude of locations is almost similar FA-Platform is the only South African wave buoy that can be considered as a deep-water buoy as can been seen in Fig 11.

Because of these reasons it is very likely that Hmax recordings will be a bit higher as well as the 24-hourly Hmax slope and maximum 6-hourly slope.

6.2 Weather patterns responsible

Concluding that obvious similarities and differences of extreme wave event characteristics exist between wave recording locations, it has to be emphasised that the main reason for these differences are the atmospheric conditions along the coast of South Africa.

For every identified extreme wave event the weather pattern responsible for that event is identified, which resulted in the vast majority responsible for extreme wave events are cold fronts. Especially at the south coast the cold fronts are responsible for almost 100% (including "explosive" cyclogenesis) of the events. The reason for this is that, cold fronts are usually associated with consistent high wind velocities with a sufficient long duration, a great fetch area in the southern ocean, and no obstacles such as landmasses. When rounding the south coast it becomes evident that other weather types such as coastal lows and cut-off lows are gaining importance for the initiation of extreme wave events. At the KwaZulu-Natal coast even tropical cyclones have be taken into consideration.

The majority of extreme wave events were distributed over the winter months (June, July, Aug) as discussed in § 6.1 Extreme wave event characteristics. This is due to more frequent and more intense cold fronts present in the southern oceans and also due to the shift of the westerly conveyor belt to a higher latitude in winter, so cold fronts have the opportunity to come closer or hitting the continent. Therefore it is obvious that the majority of weather patterns responsible for the extreme wave events will be distributed in the winter months. 56% of the weather patterns occurred in the winter, while 25% occurred in spring and 18% occurred in Autumn.

The velocities of cold fronts for the south coast is estimated as 48.4 $kmhr^{-1}$, which is 8 $kmhr^{-1}$ faster than the average velocity estimated by Van Loon (1967) for winter. This inconsistency of results is probably, due to the extra input of velocity during intense cold fronts, due the front rotating about the parent low imparting an extra velocity to the front (Hunter, 1987).

Estimated velocities for cold fronts range between 14.2 $kmhr^{-1}$ and 84.3 $kmhr^{-1}$ an hour, which is in good agreement with the velocities measured by Hunter (1987) and van Loon (1967) who indicated that velocities of cold fronts up to 90 $kmhr^{-1}$ are encountered. Hunter (1987) estimated velocities up to 120 $kmhr^{-1}$, for the explosive cyclogenesis event in May 1984. It has to be emphasised that velocities calculated for this dissertation is the average velocity over 24 hours and is therefore a bit lower than the velocity calculated by Hunter (1987).

Propagation speeds of cold fronts can have a great influence on the wave characteristics, especially when the propagation speed of the cold front exceeds the propagation speed of the wave spectrum. With an average of 48.4 $kmhr^{-1}$ the velocity of the cold fronts is most of the times faster than the group speed of waves (Refer to Table 2), which will result in less energy transfer from the atmosphere to ocean. But when propagating velocities of cold fronts are situated between 40 $kmhr^{-1}$ and 45 $kmhr^{-1}$ (Tp between 14 and 16 s) there is a constant input of energy to the ocean, which results in an extremer event

The cold fronts coming from the southern oceans and passing Gough Island propagate faster than when arrived at the Agulhas Bank. In some occasions the Indian high-pressure system blocks the cold front and cause decreasing propagation speeds as well as a deflection of the track to a more south easterly direction instead of easterly.

Propagation speeds of coastal lows and cut-off lows can be very low because these systems are trapped between anticyclones or between the continent and Madagascar and can stay at almost the same location for several days before dissipating and cause a long duration of an event, like event 3 at Richards Bay.

Comparison of intensities of the weather patterns ("explosive" cyclogenesis", coastal lows, and cold fronts) responsible for the extreme wave events follow very similar patterns compared to the wave characteristics along the coast. Cold fronts at the south coast are similar, with slightly lower intensities at Agulhas Bank, but when rounding the south coast the average intensity changed from 980 mb to 1000 mb at East London. This is one of the main reasons why events are less extreme at the east coast. The dissipation of the cold fronts and the Indian high are playing an important role in this process and have to be researched further in detail.

Explosive cyclogenesis events have very low center pressures and can therefore be encountered as important systems creating extraordinary events like event 5 at Slangkop (May 1984).

The track of weather systems responsible for events is relatively straightforward. The vast majority of cold fronts are propagating with an easterly direction. However coastal lows and cut-off lows have a greater array in which they propagate. Tropical cyclones come from a north easterly direction.

It is important to analyse 6-hourly weather bulletins instead of the daily weather bulletins as done for this study. When using the 6-hourly weather bulletins more reliable results can be obtained, for researching the synoptic weather conditions responsible for the extreme wave events. Especially when researching the velocity over time and tracks followed over time. Due to a constraint in time and the difficulties to obtain the 6-hourly weather bulletins it is chosen to analyse the available daily weather bulletins from SAWS. The 6-hourly bulletins can only be analysed as a hard copy at the South African Weather Service archive in Pretoria, South Africa.

However the 24-hourly bulletins give a good indication of the velocities, tracks and intensities of the atmospheric conditions responsible for the extreme wave events. Analyses of the 24-hourly bulletins also conclude that differences exist between the southern Cape and east coast.

6.4 Methodology

All the extracted datasets had different time intervals between recording years and locations. Therefore it is chosen to calculate all the slopes with 6-hourly intervals, even when recording intervals where hourly. This method caused that not all data points are included in the calculation and will result in less accuracy.

As discussed previously, it is extremely difficult to analyse all the weather patterns with the daily weather bulletins instead of the 6-hourly weather bulletins. Within 24 hours the situation can be totally different without knowing what is really going on. Identifying the weather patterns responsible was a hard task because of this reason.

It is also very hard to identify cut-off lows without having any information available of pressure gradients at 850 hpa (the upper atmosphere).

The weather bulletins are an artist impression of the real situation and only give a good indication of the actual situation.

6.4 Impacts of extreme wave events

To show the devastating force of storms (extreme wave events) the impacts of the identified events will be discussed in this paragraph. It will become clear that during almost every event some damage or impacts on shipping, breakwaters and harbour activities has occurred, due to the severe weather and extreme wave conditions. In the first section a few examples are given of impacts of events on shipping. Not all reported impacts on shipping are listed, but it will give a sufficient indication of the impacts that arise during extreme wave events. This information of impacts on shipping is obtained from Lloyds insurances salvage arbitration branch, newspaper clippings and UCT ship law's website (see references).

The impacts of events identified for this thesis are not only confined at the ocean or ocean-land boundary, but severe winds associated with these events can also cause significant damage to human developments which happened during the explosive cyclogenesis at the 16th of May, 1984. Considerable destruction of property occurred across the Peninsula and south western Cape, especially Somerset West and Suurbraak suffered from damage by strong winds (Shillington and Jury, 1986). Many millions of Rands damage were inflicted by the heavy seas on the main breakwater in Table Bay and the Greenpoint outfall pipeline as another casualty (Hunter, SAWS website).

During event 6 (1991-08-04) at Richards Bay, the passenger liner *Oceanos* came in trouble off East London. On board were 581 passengers (including crew) and the ship capsized 12 hours after the first flooding. No casualties were reported. During the same event the VLCC Norwegian came in trouble and this storm caused severe damage. The accident with the *Oceanos* was the reason to initiate wave-recording at East London.

During event 17 at Slangkop (1994-06-18/22), the *Appolo Sea* sank, which caused 10,000 penguins to be oiled and from these 10,000 penguins 5,000 died. *Appolo Sea* had 2400 tonnes of fuel on board. During the same event the *BOS 400* was towed around the Cape, but it broke loose and ended up on the rocks.

Pic 2: Ikan Tanda grounded on the coast of Scarborough

During event 28 (2001-09-05) at Slangkop, the cargo vessel *Ikan Tanda* from Singapore grounded at the beach of Scarborough after a small fire that broke down the engine. The cargo of *Ikan Tanda* were fertilizers (Potassium Nitrate, Potassium Sulphate, Potassium chloride and Boronat) and fuel.

During event 15 at East London and 16 at Richards Bay (2002-07-15/19), *Nino* from the Marshall Islands grounded at Coffee Bay. The cargo 7,700 tonnes of gasoline and gas oil. During the same event the Portugese cargo carrier *Sagitarius* grounded on the Rocks at East London.

Pic 3: *Jolly Rubino* grounded at the coast at St. Lucia

During event 17 (2002-09-13) at Richards Bay, the Italian cargo vessel *Jolly Rubino* grounded at St. Lucia, which is an important conservation area. During the storm a fire broke out and the crew abandoned the ship and left her in the mercy of onshore winds and currents. *Jolly Rubino's* cargo was 450 metric tonnes of oil and some of it was leaking and formed a great threat to St Lucia's wetlands.

During event 33 (2003-09-17) at Slangkop, the US *Sealand Express* grounded at the beach in Milnerton. Its cargo was 500 tonnes of crude oil, 56 tonnes of unprocessed uranium, industrial chemicals and it was leaking some of the flammable chemical propyl acetate.

It has to be emphasised that many more cases are recorded from grounded, sunken or ships in trouble along the South African coast. These examples show that the whole South African coastline is subjected by impacts from shipping disasters during storms.

When finishing proposals of the design wave height of breakwaters for the new Coega harbour near Port Elizabeth, an event at East London took place with south easterly wave directions and a significant wave height of 9.3 m. Significant wave heights during this event at 12-06-1996 were never recorded before at East London and caused the proposals of the breakwaters heights to be altered.

Pic 4: Overtopping of breakwater by waves and erosion on the lee side at 5 Sept 2001 (CSIR 2001)

Other impacts that might occur during extreme wave events is overtopping of coastal structures by waves. The average overtopping rate is an important design parameter for seawalls breakwaters and tidal pools. Often it is not feasible from an economical point of view to construct a seawall or breakwater high enough to prevent overtopping completely (Luger, 1991). Therefore during extreme wave events the breakwaters are too low and in a lot of cases the waves will overtop the structures and cause damage to the breakwaters or structures behind the breakwaters.

South Africa has a coastline of 2,798 km and about 1700 km of the South African coast is made up from sandy beaches. Some of these areas are very dynamic and the influence of storms on these areas can be significant. In some cases the shores of these areas are developed and erosion due to storms may be a disaster for many houses.

Most of the commercial harbours are situated in bays that protect the harbours from the predominantly south westerly swells like; Mossel Bay, Coega and East London. But on occasion cut-off lows or other weather patterns create significant south easterly swells, which can cause damage to the dolos armouring of breakwaters or other structures in these harbours.

As an example it is concluded that the most severe wave attack on the main break water at Mossel Bay harbour will come from easterly or south south westerly waves. The most likely peak periods of extreme wave spectra were found to be 9.0 and 13.5 s for easterly waves and 13.5 and 15.5 s for south south westerly waves. With extreme easterly events it was concluded that the waves break before reaching the breakwater (CSIR report, 1988). Serious damage to the dolos armouring of the main breakwater of Mossel Bay Harbour in 1986. East London harbour breakwater was damaged in 1996.

Not only swells or wind waves can impact the harbour environment. Other wave phenomena, which can cause problems to harbours, breakwaters and the navigation into bays and harbours are listed below:

- Range waves (produced by the passage and dissipation of storm centers traveling over the Atlantic Ocean from north to south some 500 to 1500 miles west of South Africa, which cause ranging of moored and quayed ships and water level differences in harbours. The periods are from 25 seconds up to 12 minutes and are observed as ground swells. (form very minor problem along South African coast) (Joosting, 1963)
- Barometric waves and tsunamis (very seldom cause difficulties in harbours)
- Tides

Impacts of waves wind and tides causes erosion of sand from the spending beach breakwater (= breakwater from sand) at Saldanha Bay. The rate of erosion was approximately 50.000 m3/year. The erosion was determined by a preliminary result from CSIR 1985. (CSIR, 1988)

Regular surveys of the Richards Bay breakwaters revealed significant damage on the North Breakwater head and the South Breakwater trunk. Preliminary repair work has been done in 1985 (South Breakwater trunk) and in 1986 North Breakwater head. There is also a recent report about the impacts of waves and wind on shipping at Richards Bay, where visual information gives a clear picture of the problems associated with vessels arriving or departing at Richards Bay.

6.5 Trends in annual exceedances

To determine if it is getting stormier along the coast of South Africa the frequency of exceedances are plotted for each location and fitted with a trend-line. No firm conclusions can be drawn for such small datasets. However, Figure 24 till 27 can be used to illustrate the approach.

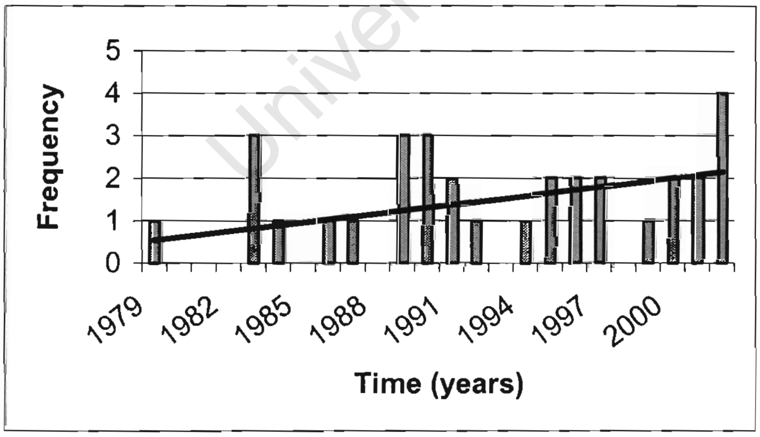


Fig 24: Number of exceedances a year at Slangkop

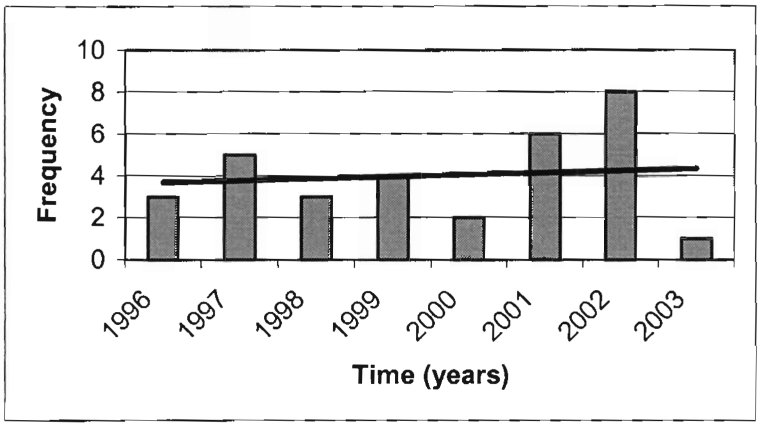


Fig 25: Number of exceedances a year at FA-Platfrom

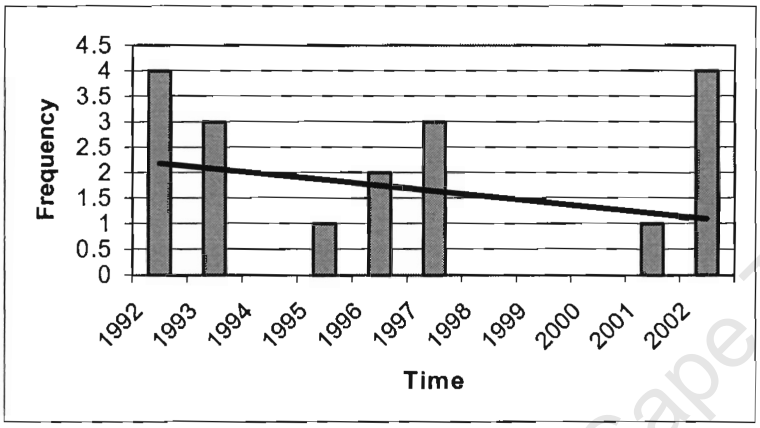


Fig 26: Number of exceedances a year at East London

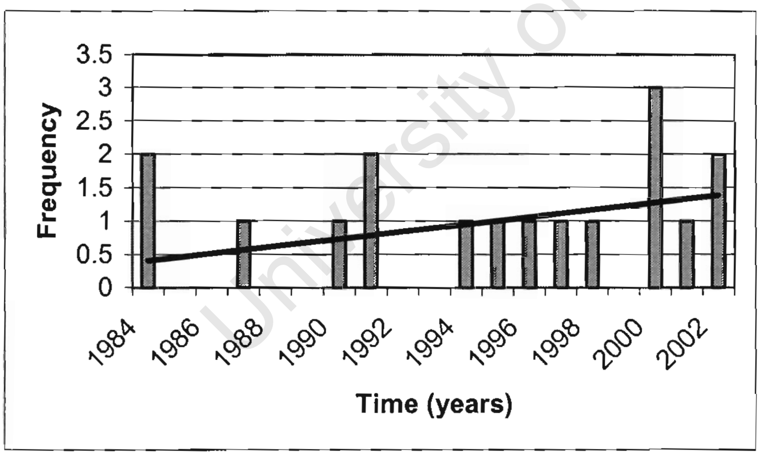


Fig 27: Number of exceedances a year at Richards Bay

This suggests that at Slangkop and Richards Bay the number of exceedances a year are increasing. These two locations are operational for the longest time and therefore give a better indication. At FA-Platform the number of exceedances increases a little while at East London the number of exceedances decrease. These graphs give only an indication and a longer database has to be analysed to determine real differences over time. And even if frequencies of events increased over the past 25 years the question has to be raised, is this due to the global climate change or due to other circumstances such as the El Niño Southern Oscillation (ENSO)?

Do more events occur during El Niño years?
During or just after El Niño the climate of the world variate from its mean and strong anomalies will be present. According to Colberg F. et all (2004) Sea Surface Temperatures (SST's) and sea-level pressure anomalies in the South Atlantic are in direct relation with El Niño events. Therefore there is a possibility that more frequent or more intense storms occur in the Southern Ocean. For more information on El Niño and La Niña, please refer to Philander S.G.H. (1992) El Nino and La Nina. Journal of Atmospheric Science, Volume 42, pp 2652-2662.

Table 25: El Niño, La Niña and neutral years according to the FSU definition

1980 Neutral	1981 Neutral	**1982 El Niño**	1983 Neutral	1984 Neutral
1985 Neutral	**1986 El Niño**	**1987 El Niño**	*1988 La Niña*	1989 Neutral
1990 Neutral	**1991 El Niño**	1992 Neutral	1993 Neutral	1994 Neutral
1995 Neutral	1996 Neutral	**1997 El Niño**	*1998 La Niña*	**2002 El Niño**

An ENSO (El Niño-Southern Oscillation) year according to the FSU definition runs from the September of that year to the following year. For example, the 1988 La Niña runs from September 1988 to August 1989.

When analysing the exceedances during ENSO years it becomes evident that a correlation exist between these two. Especially in 2002 frequencies of yearly exceedances increase significantly. 14 of the 32 events at Slangkop were during 6 ENSO years. For a 25-year dataset this means that during ENSO years the number of exceedances almost doubled from an average number of exceedances of 1.3 and during an ENSO year 2.3.

At FA-Platform 1.4 times as more events were identified during ENSO years.

At East London the identified events during ENSO years doubled.

At Richards Bay there is no significant increase during the ENSO years. This is probably due to the cold fronts, which are assumed to be mostly impacted by ENSO events, are a less predominant feature on this stretch of coast.

Only one La Niña year could be analysed for Slangkop and Richards Bay and at both locations in 1988 no exceedances occurred but in 1989 three exceedances occurred at Slangkop. In 1998 at Slangkop and East London no events were identified, but at FA-Platform three event were identified and one event was identified at Richards Bay.

More research has to be undertaken on this subject, but a preliminary statement from this comparison is that cold fronts are more frequent and maybe more intense during or just after ENSO years.

6.6 Recommendations for further research

If this dissertation project was not subjected to a time frame of 4 ½ months, more detailed research could be undertaken about extreme wave events and the atmospheric conditions responsible for these extreme wave events.

Especially comparison between extreme wave events and the correlated weather patterns could be analysed in much more detail. Where were the weather patterns situated during events and what is the influence of their position on the extreme wave climate experienced at the coastal belt? What is the impact of the propagation velocity of weather systems on the properties of events and individual waves? A more detailed study can be undertaken on the propagation velocities of weather patterns responsible or their intensities and tracks when 6-hourly weather bulletins are analysed.

Further research on the characteristics of the extreme wave events can be undertaken on:

- The set up criteria for this thesis can be lowered with half a meter to get a bigger dataset, so that more events can be researched, which will result in less scatter of averages and standard deviations.
- Correlation parameters can be calculated of individual wave characteristics to see what the differences are between Hmax and Hmo.
- Research can be undertaken by looking at the differences between sets of waves and to calculate the strength of the sets of waves.
- In what way is the Agulhas current influencing the extreme wave events at the East coast, by looking at the increasing wave heights and steepness of waves due to wave current interaction?
- Highlight specific extreme wave events and discuss them as separate case studies.

The deployment and maintenance (around 300,000 Rand a year) of wave recoding buoys is expensive and therefore it has to be emphasised that a denser network along the South African coast has to be sponsored by "foreign" companies that have the resources available. However it is very important to research some specific features such as for example the wave-current interaction, verification of satellite measurements for the southern ocean and the new Coega harbour, which will benefit the economy.

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https://www.lloydsagency.com/Agency/Salvage.nsf (Lloyds insurances salvage arbitration branche)
http://www.sanccob.co.za/history_timeline.htm (Info impacts of oil spills on birds)

Appendix I: Wind direction in percentage of occurrence

Winds: (CSIR report, 1989)

Saldanha Bay:
Location: Port Control Tower at 48 m above MSL
Instrument: Capricorn II Weather station (4 sec wind speed averages with instantaneous wind direction)
Period: 1985-1988

N	NW	W	SW	S	SE	E	NE
12.9	8.5	2.3	6.8	49.1	18.3	0.7	1.4

Port Elizabeth:
Location: Port Control at 40 m above MSL
Instrument: Digital display of instantaneous direction and speed
Period: 1982-1988

N	NW	W	SW	S	SE	E	NE
0.9	3.8	26.7	36.3	1.5	6.2	21.8	2.8

Durban:
Location: Signal Station on the Bluff, 100 m above MSL
Instrument: Chart recorder from which an hourly average could be obtained
Period: 1982-1988

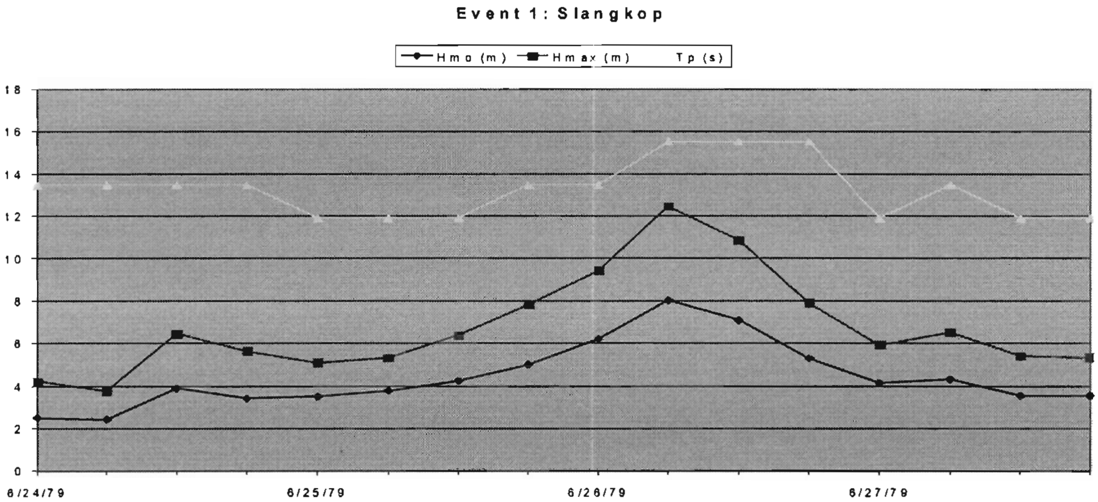
N	NW	W	SW	S	SE	E	NE
11.8	0.13	2.1	19.9	13.0	1.6	9.1	42.4

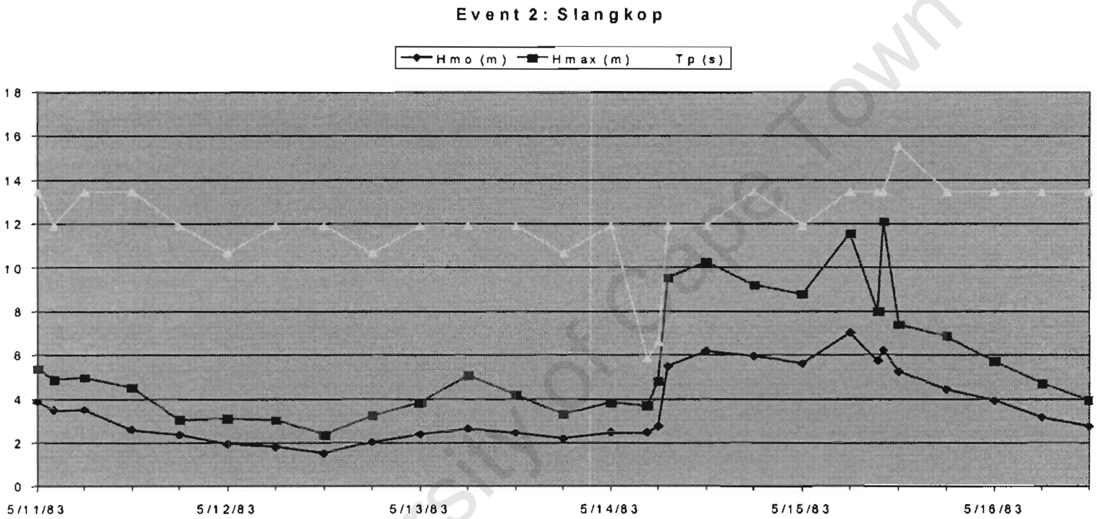
Table Bay:
Location: Port Control (Lourens Muller Building), approx. 35 m above MSL
Instrument: Capricorn II Weather Station
Period: 1986-1988

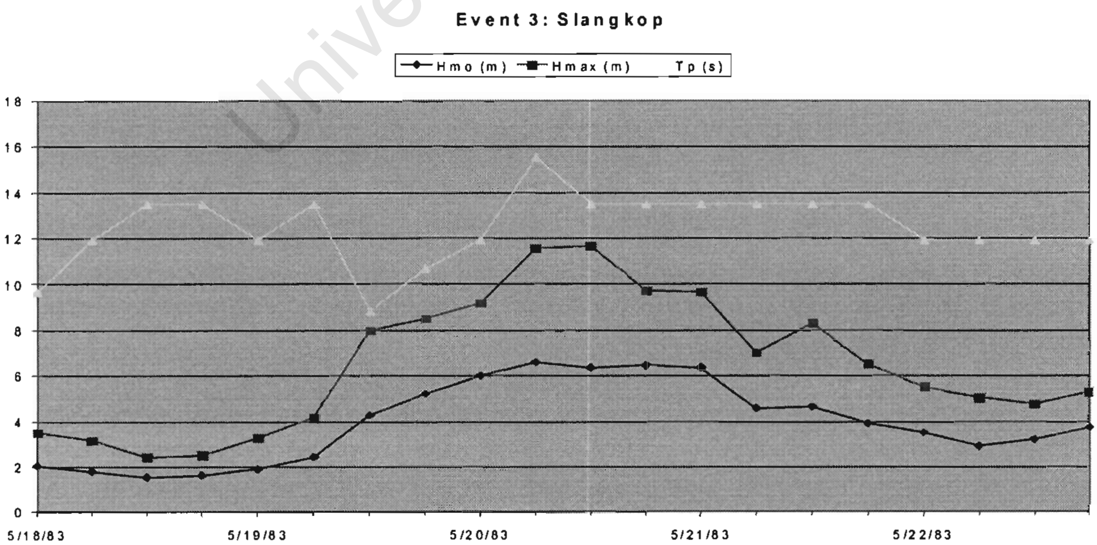
N	NW	W	SW	S	SE	E	NE
7.3	26.0	3.5	2.5	1.9	58.7	0.1	0.0

Less south and east direction due to the effect of Table Mountain.

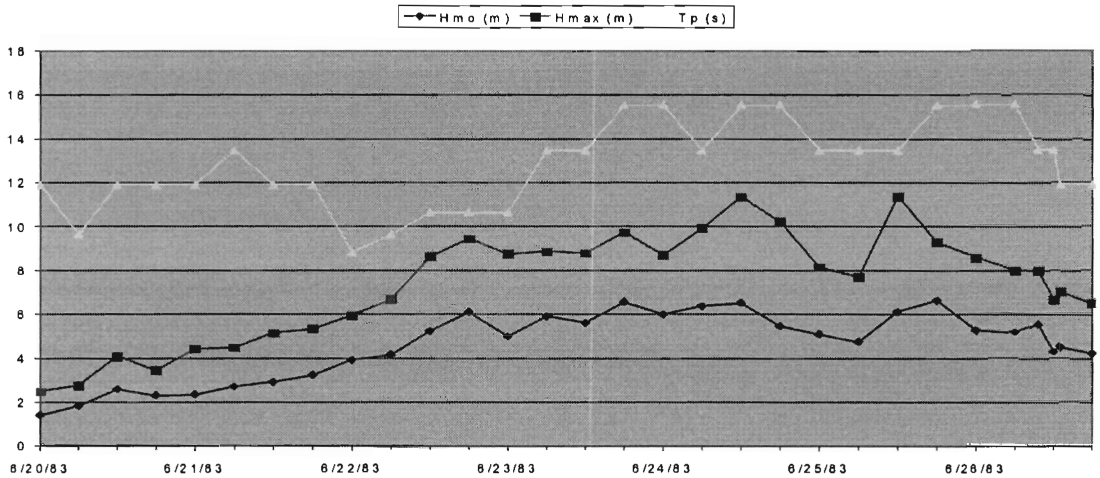
Appendix II: Graphs of events for Slangkop







Event 4: Slangkop



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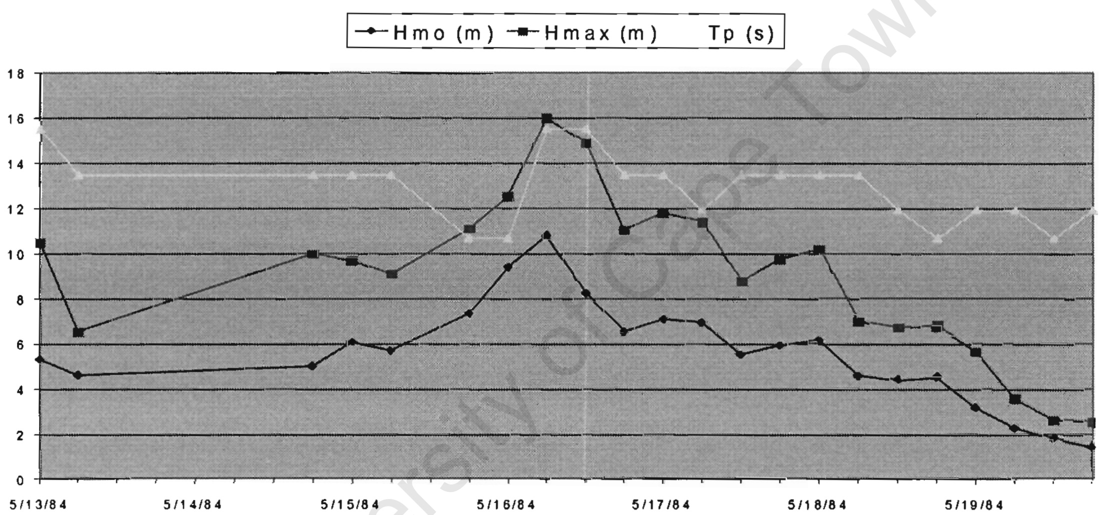

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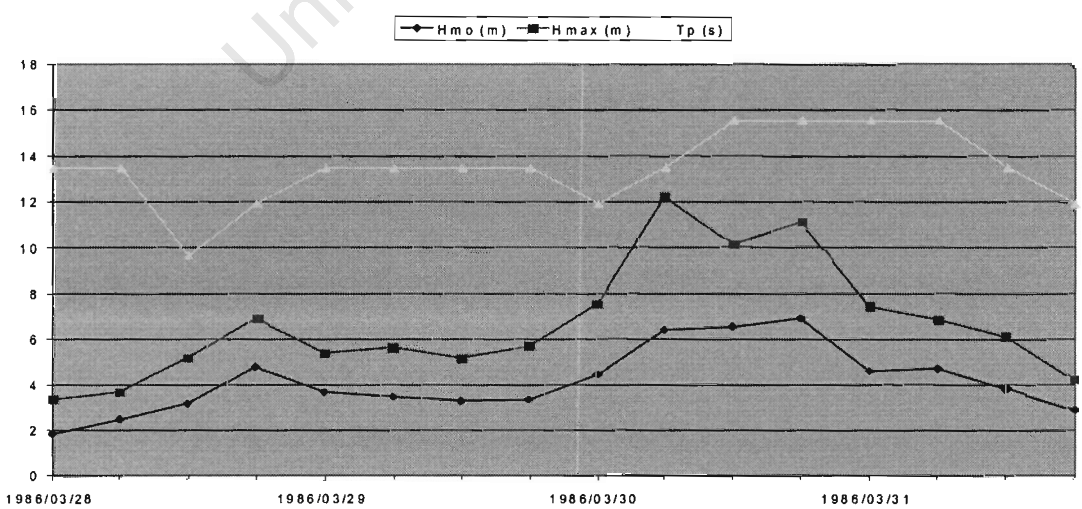

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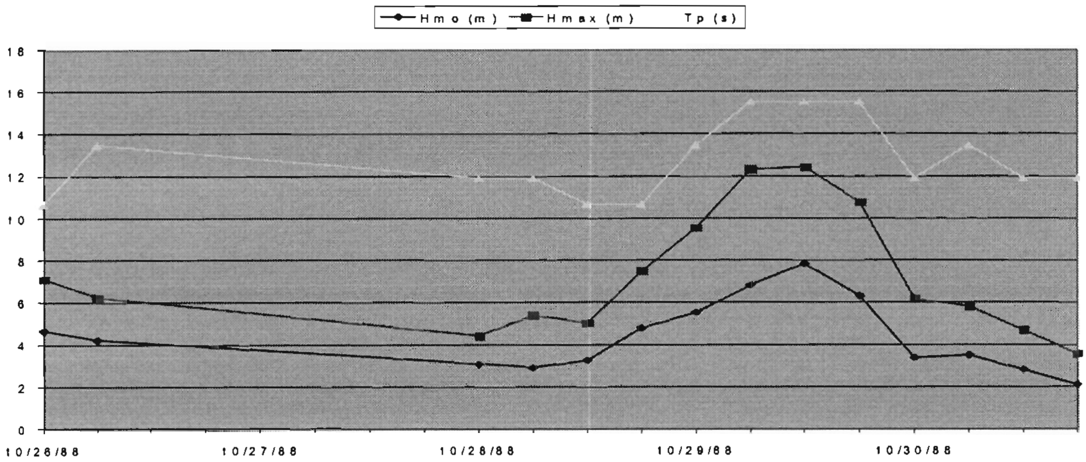

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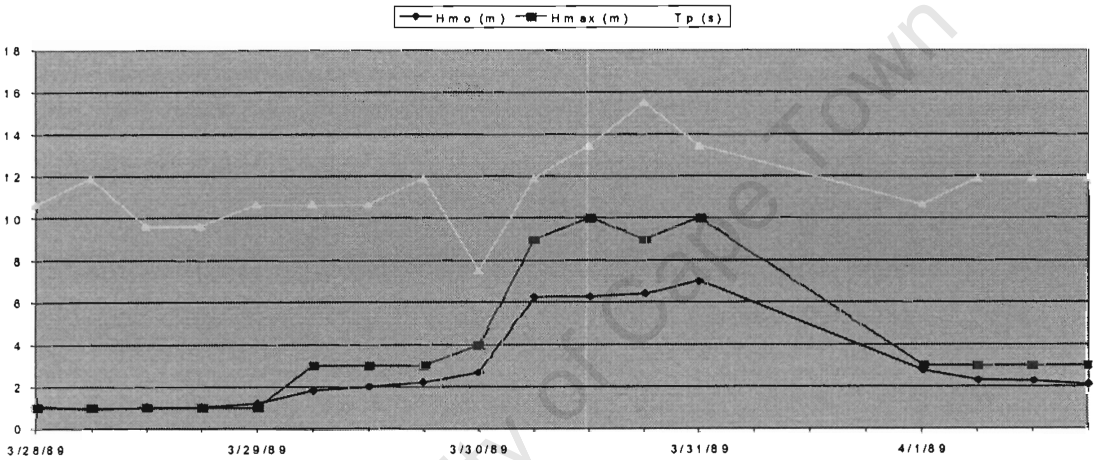
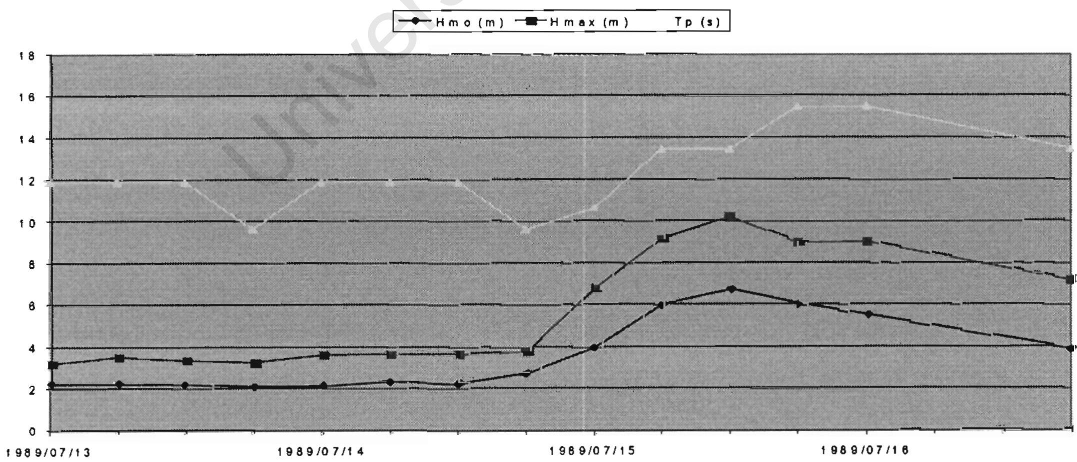


Event 9: Slangkop



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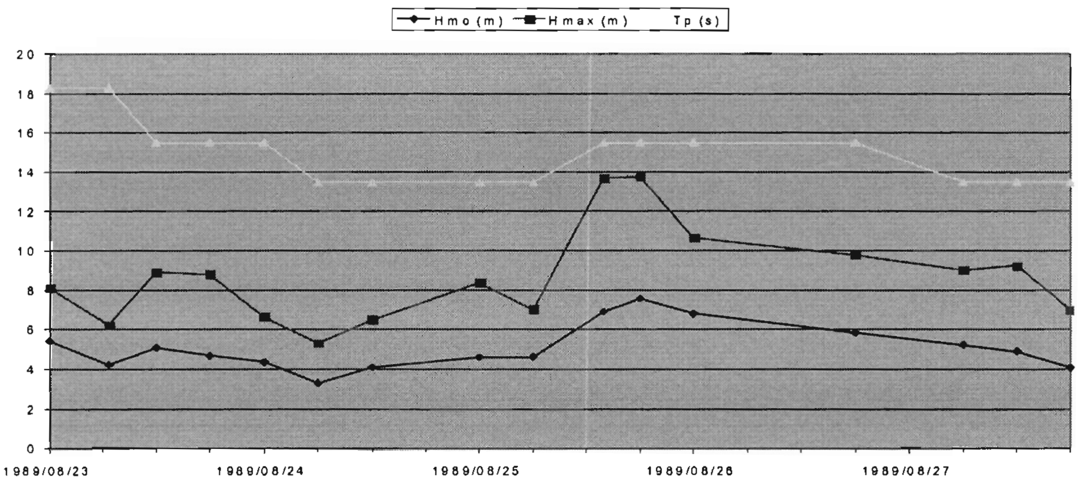

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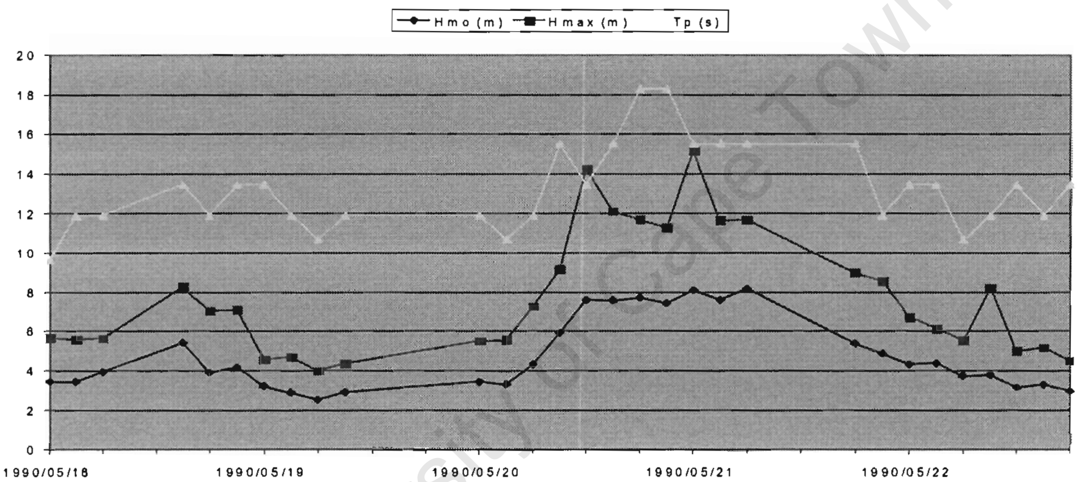

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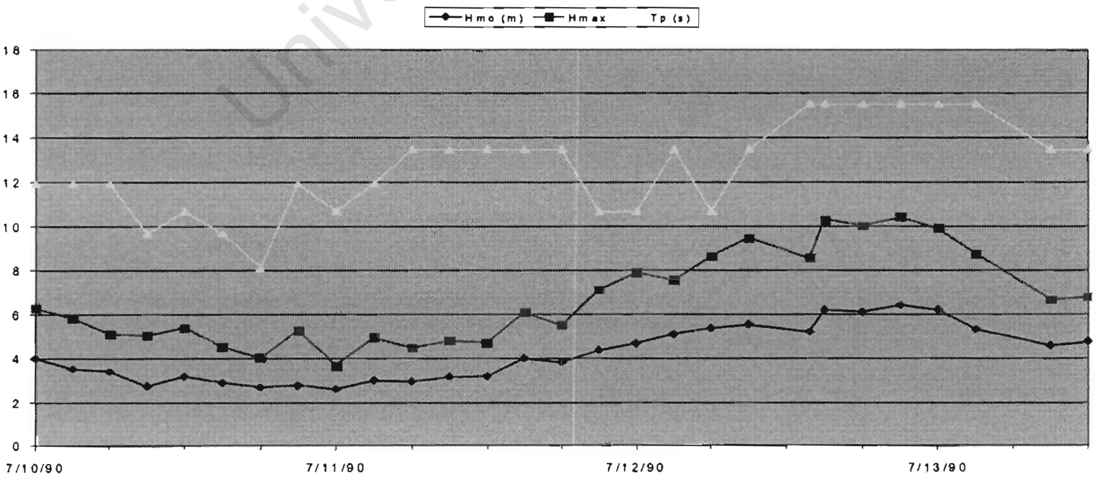

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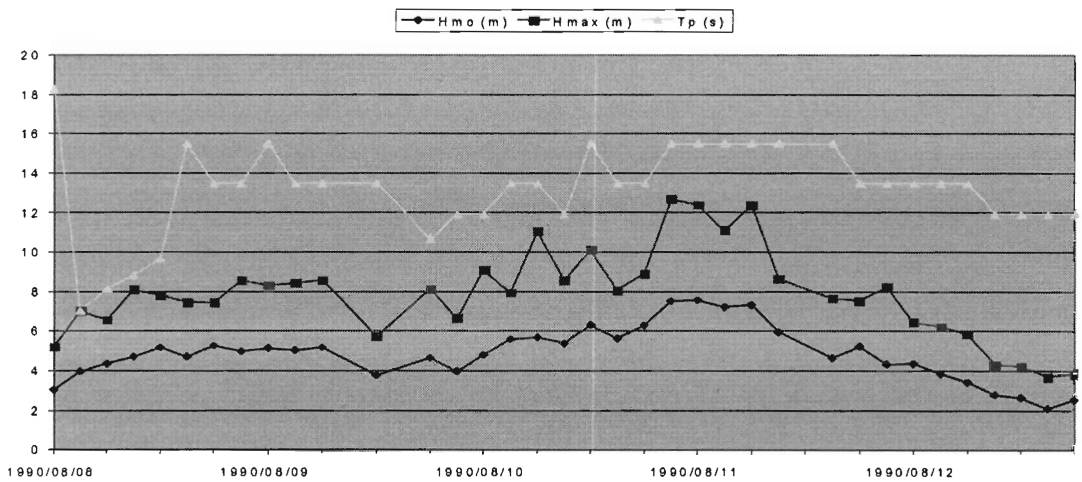

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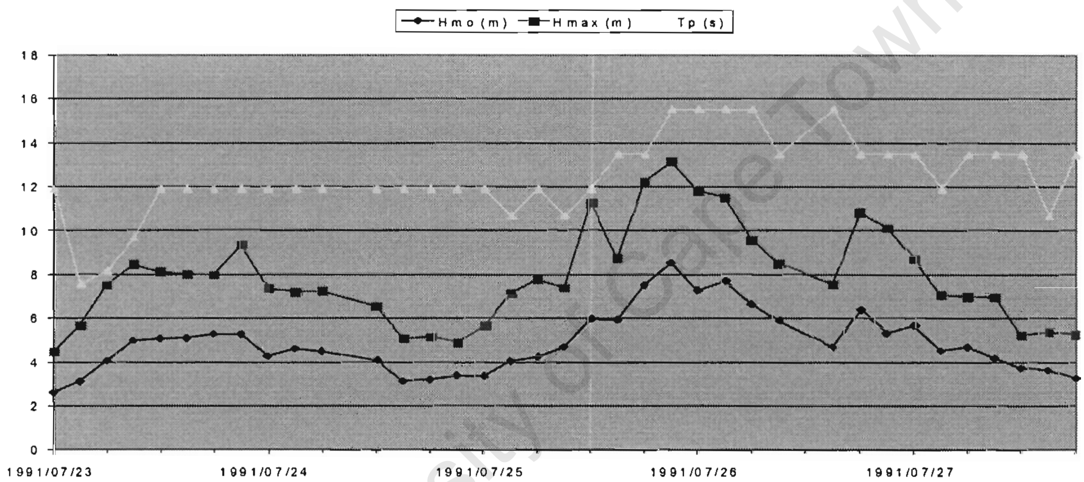
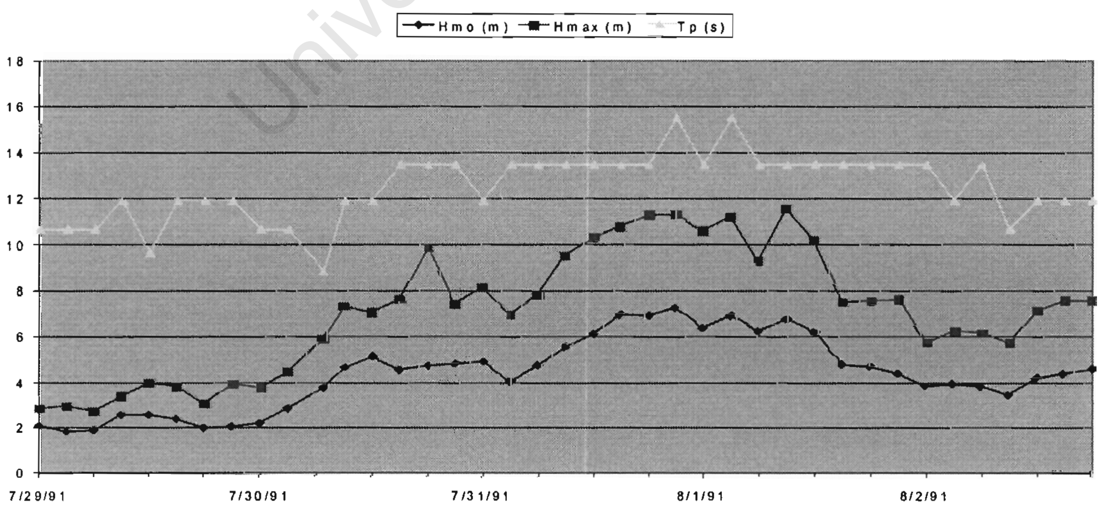


Event 15: Slangkop



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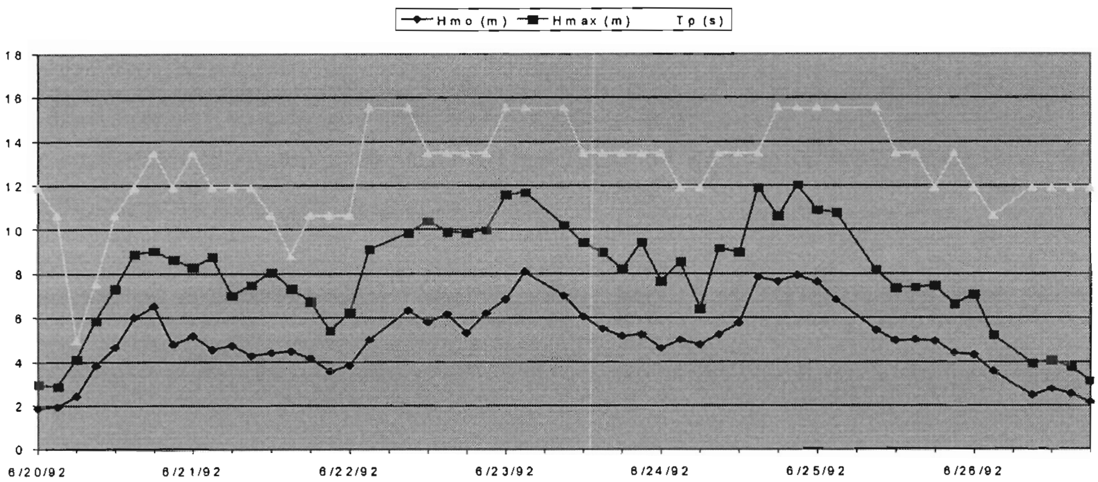
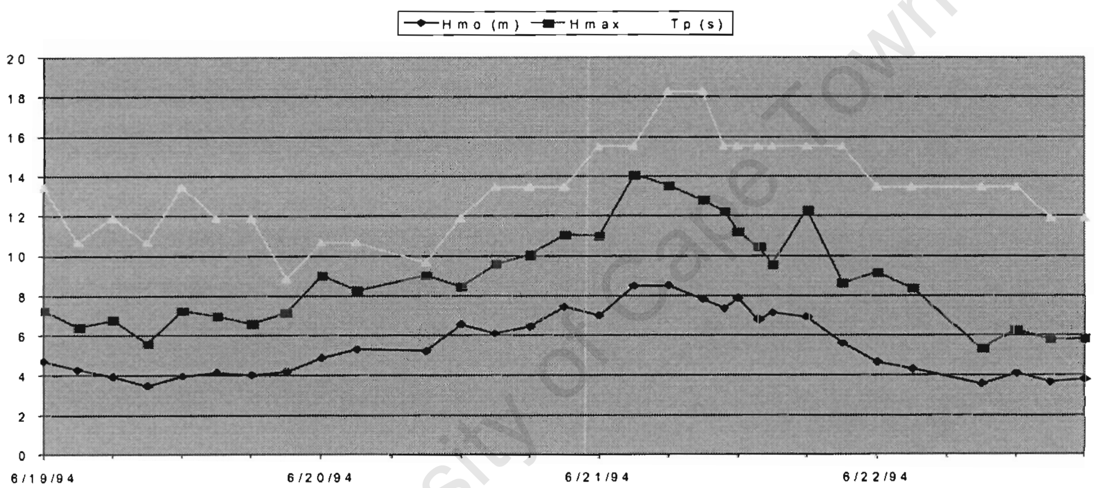


Event 17: Slangkop



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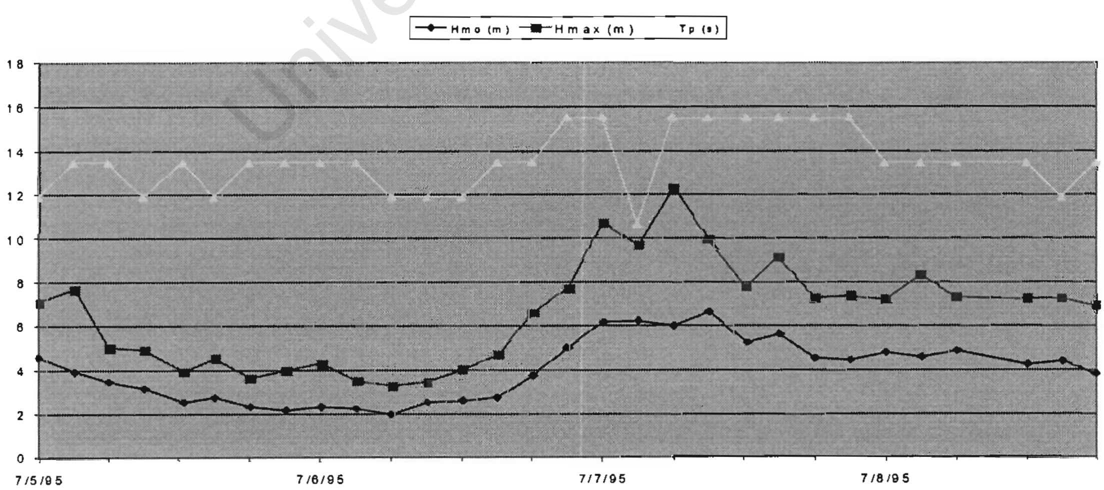

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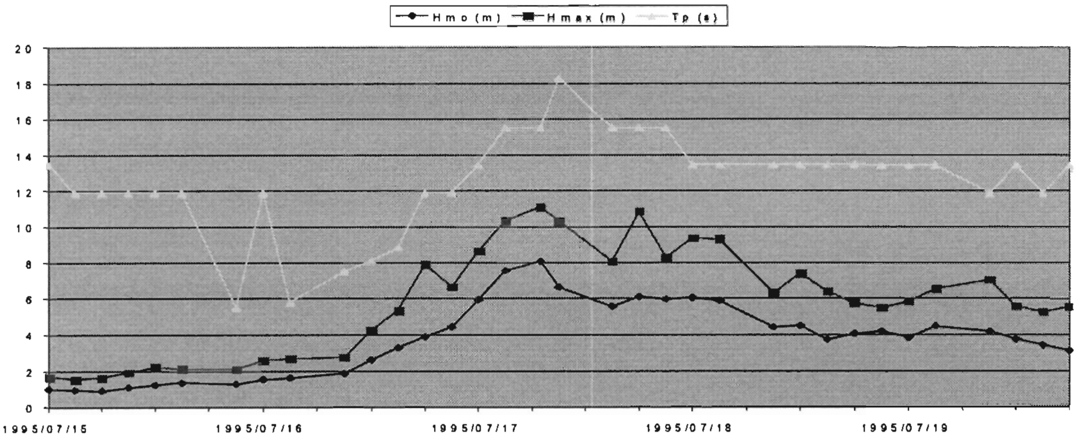

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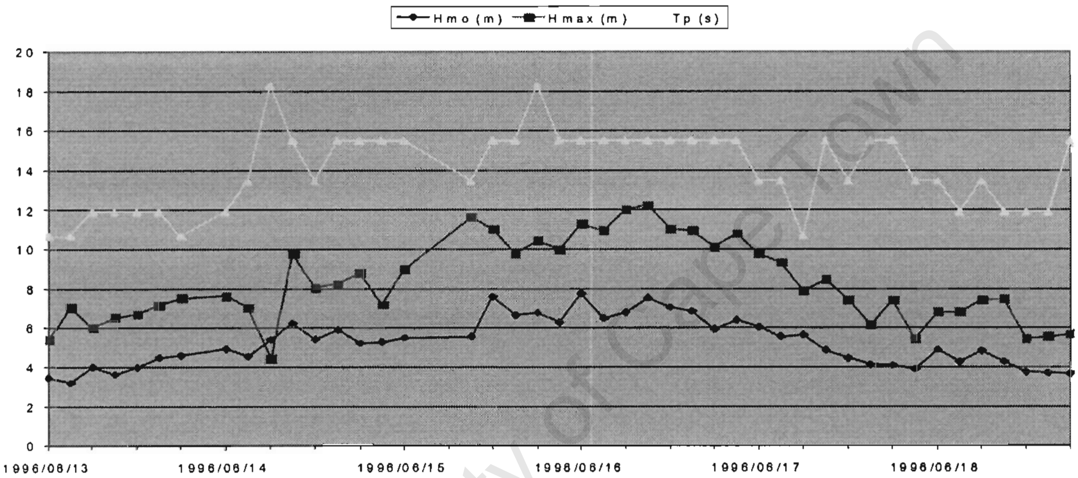
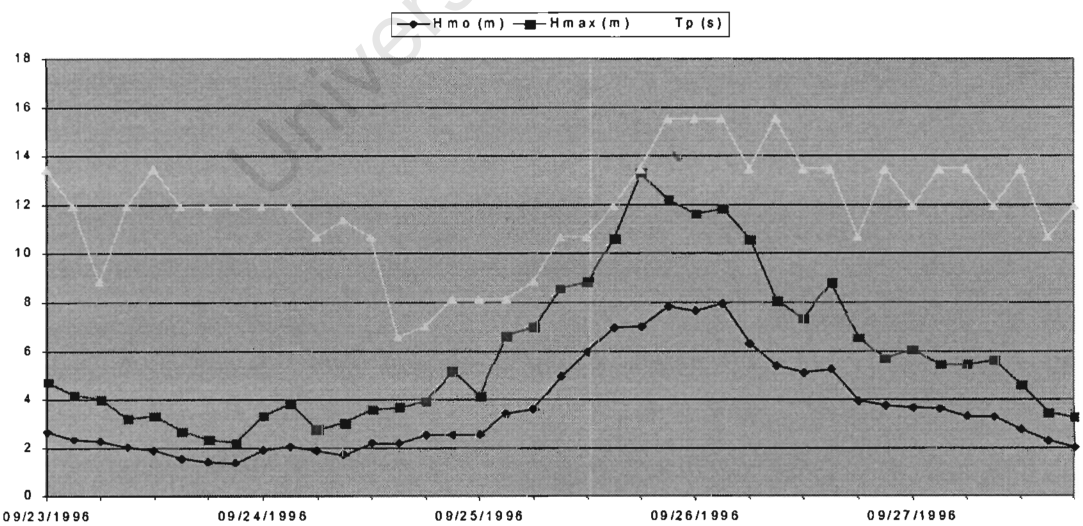
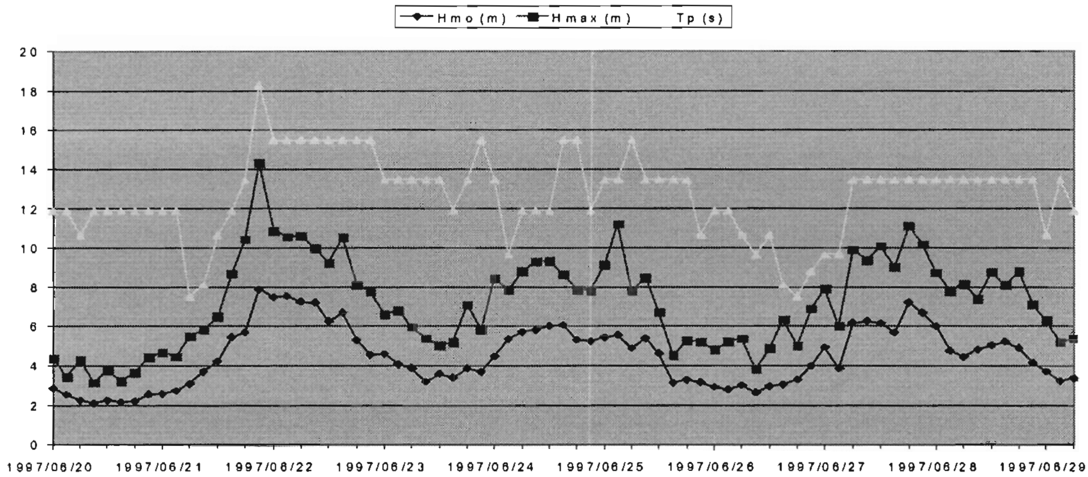


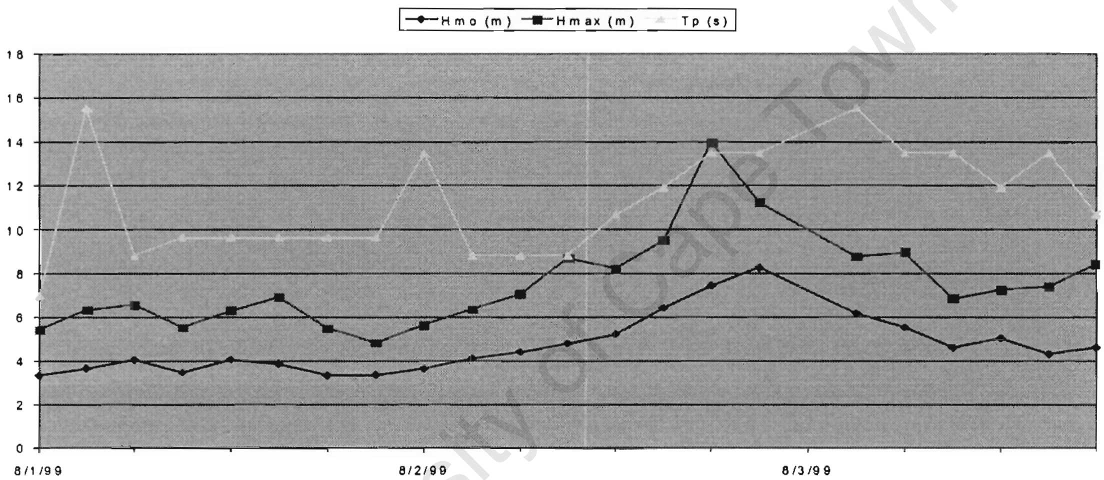
Event 21: Slangkop



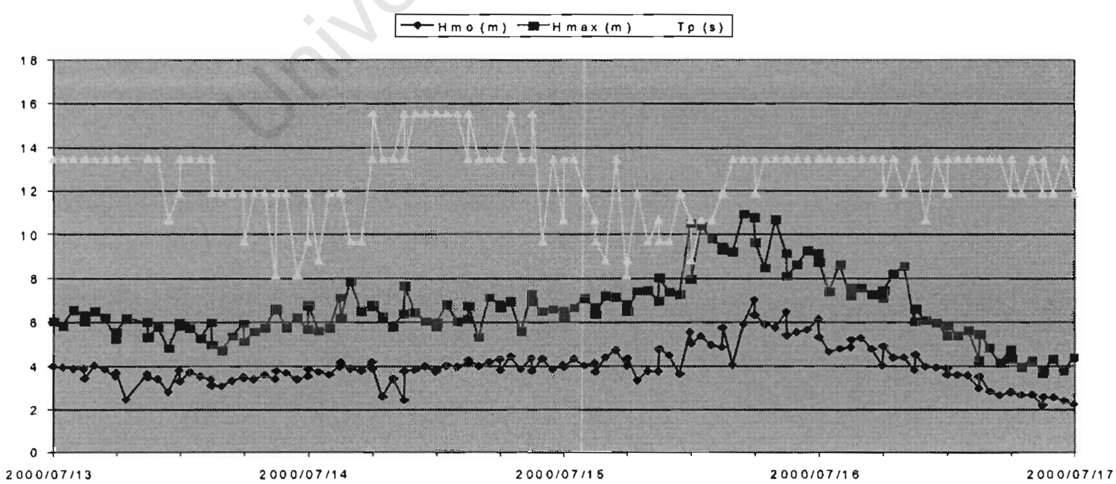
Event 22 + 23: Slangkop



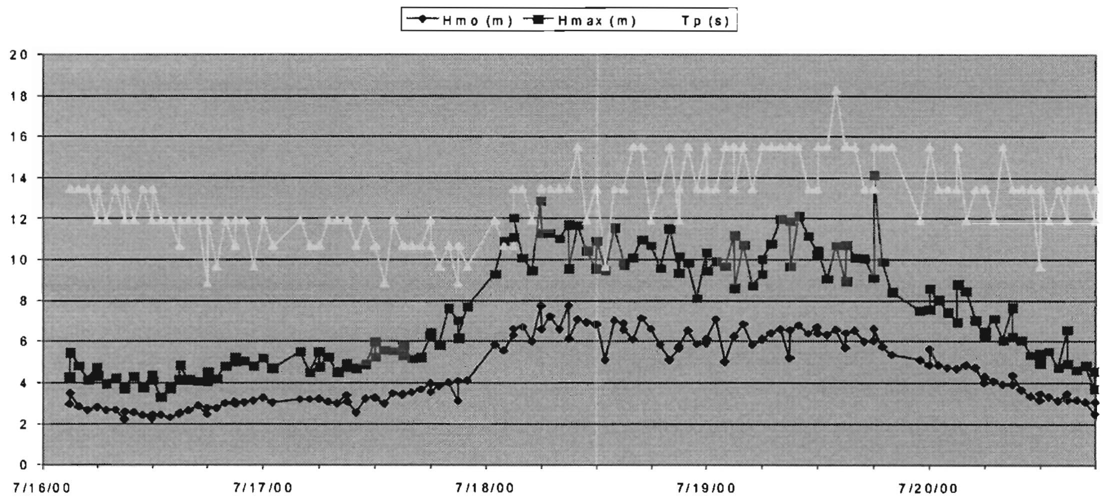
Event 24: Slangkop



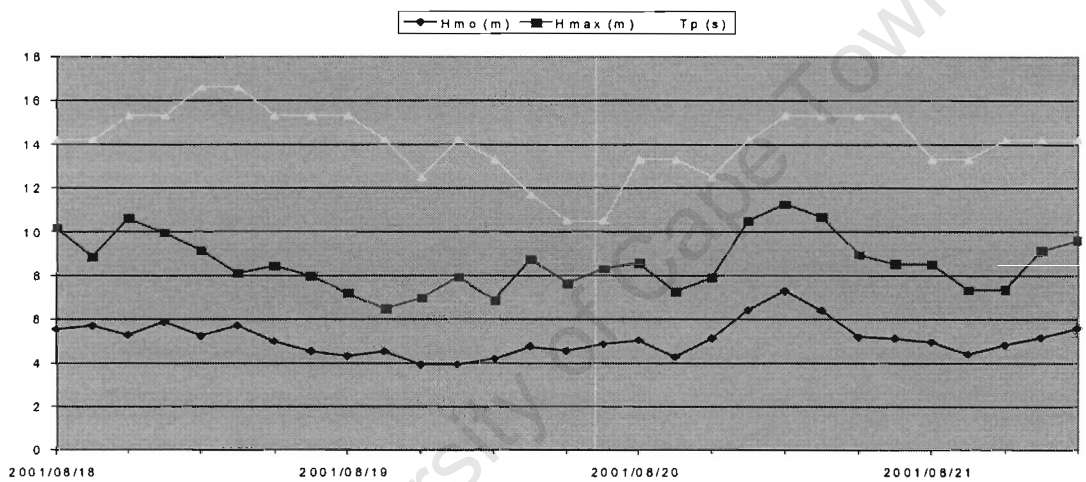
Event 25: Slangkop



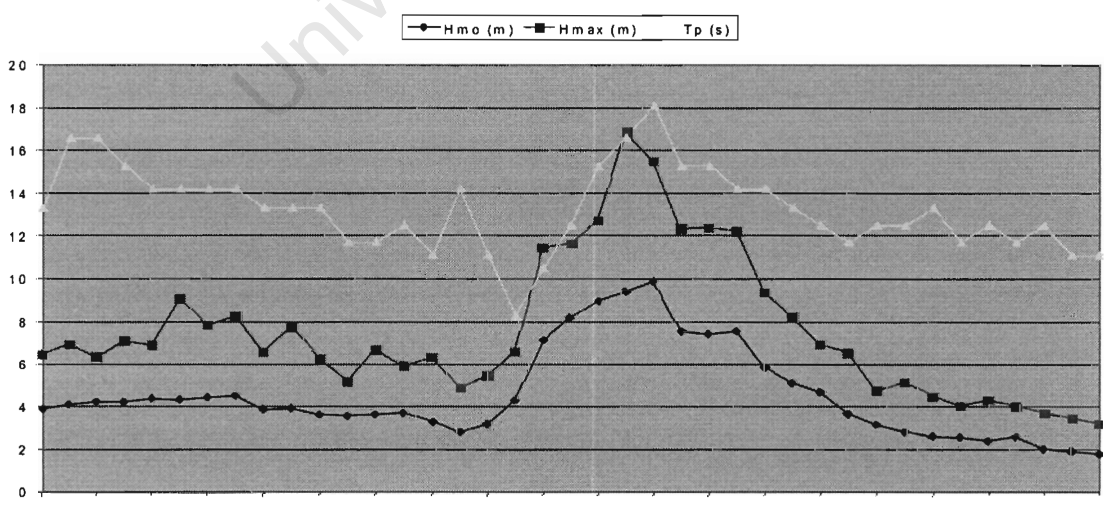
Event 26: Slangkop



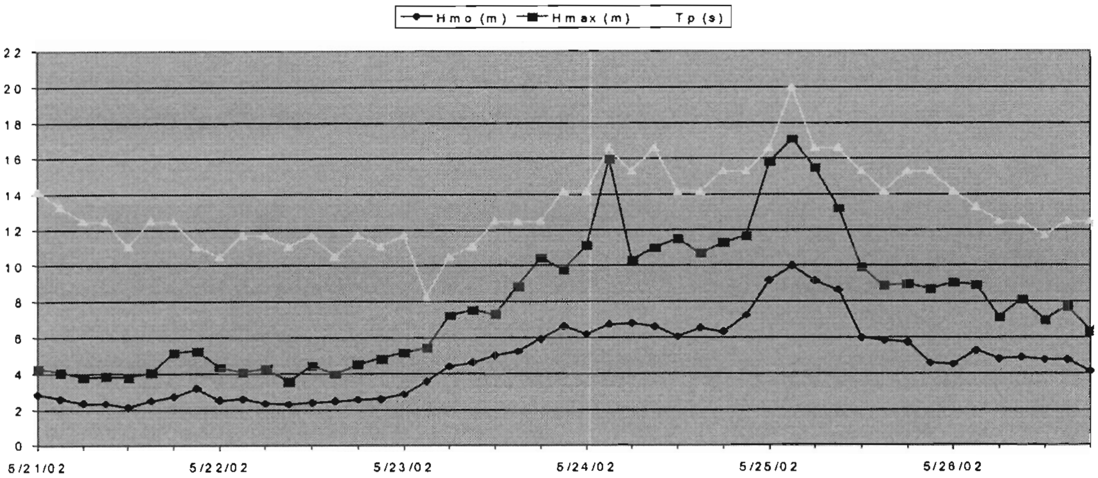
Event 27: Slangkop



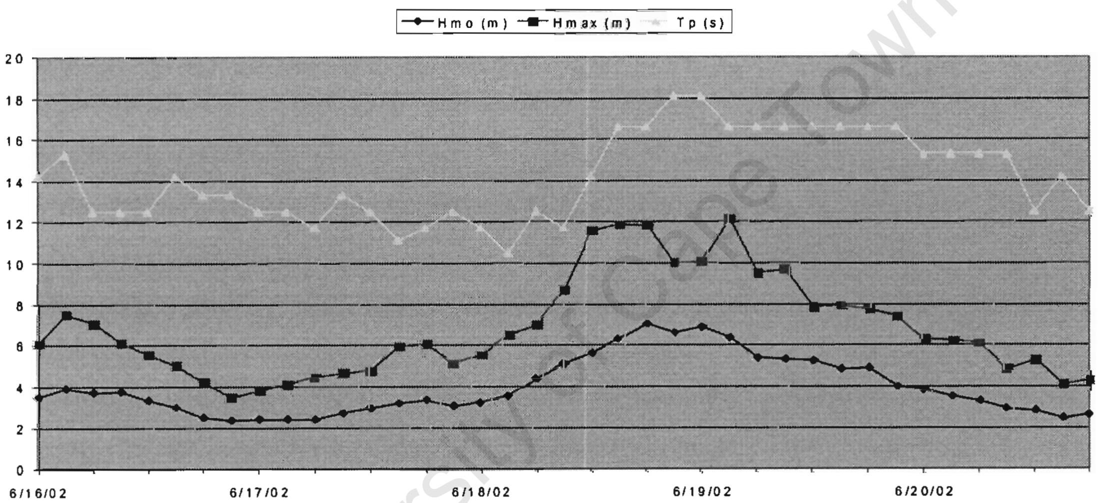
Event 28: Slangkop



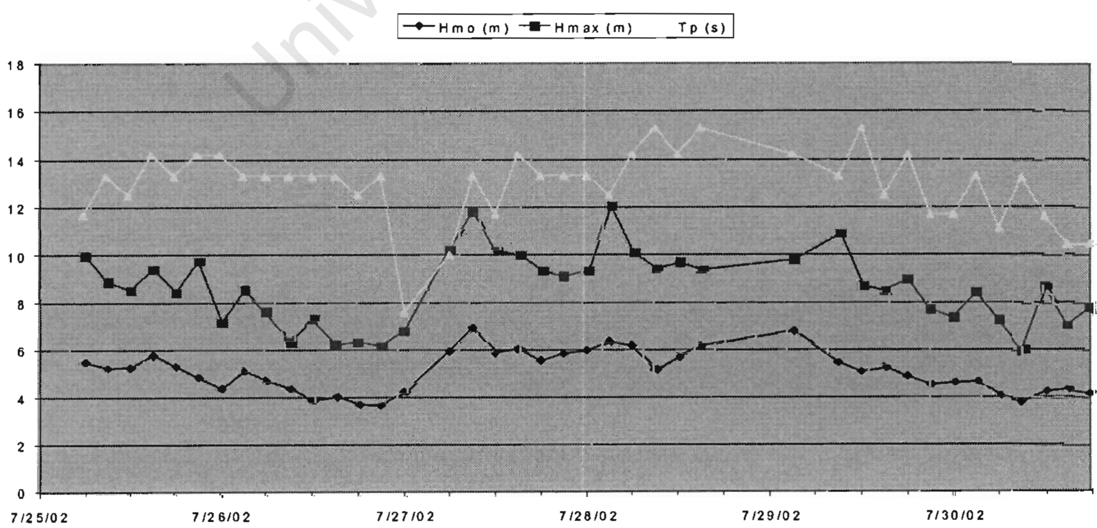
Event 29: Slangkop



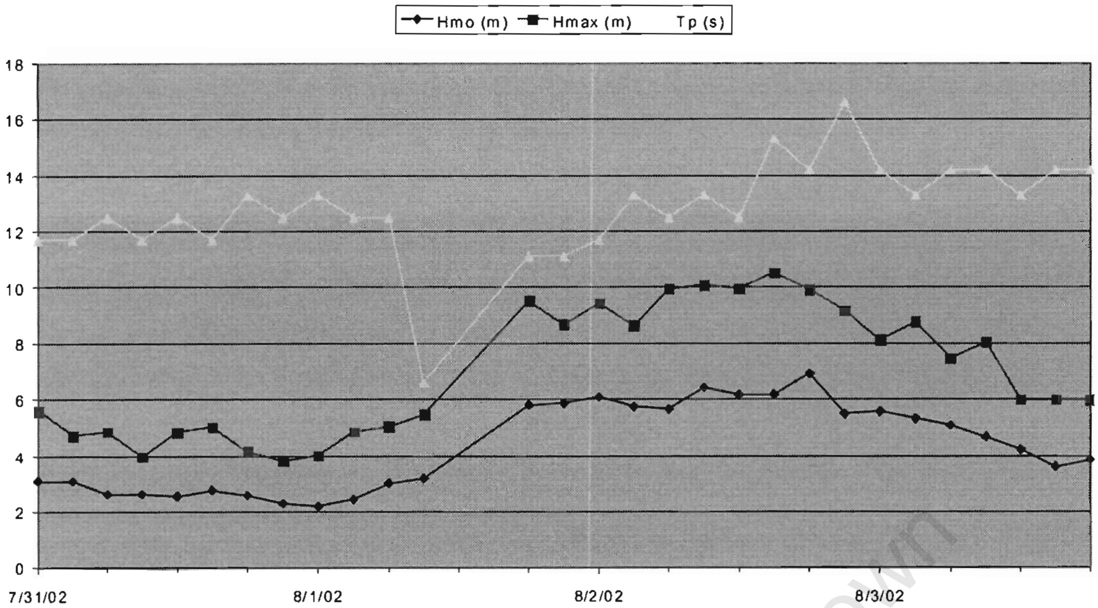
Event 30: Slangkop



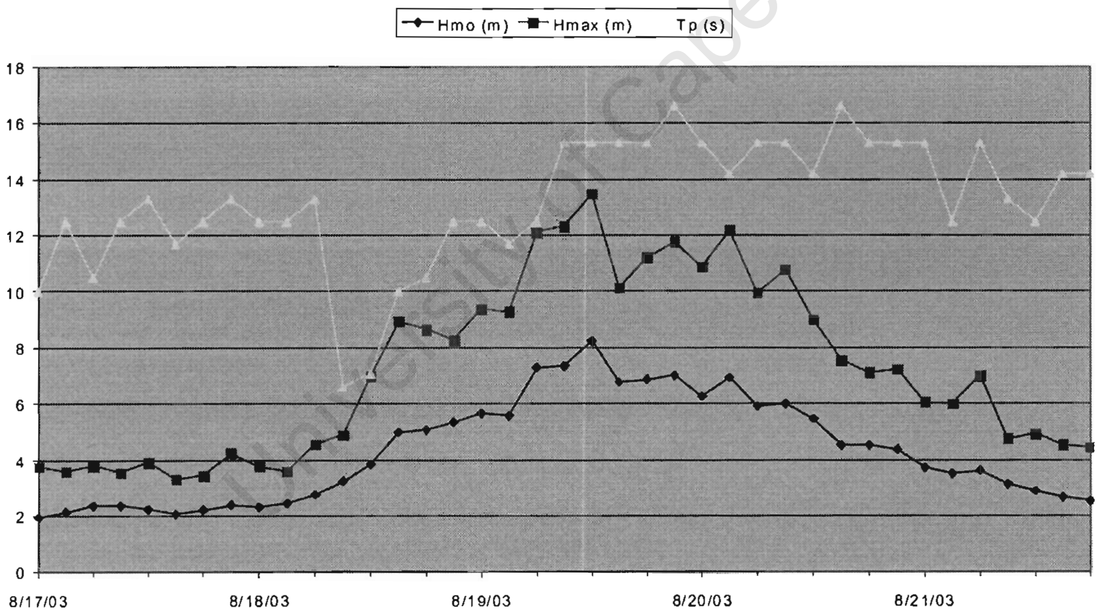
Event 31: Slangkop



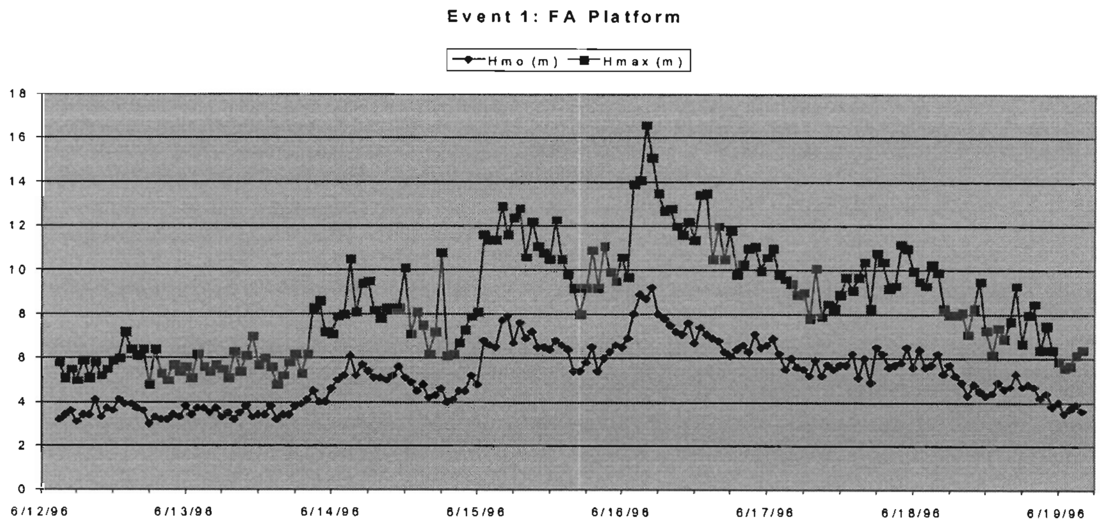
Event 32: Slangkop

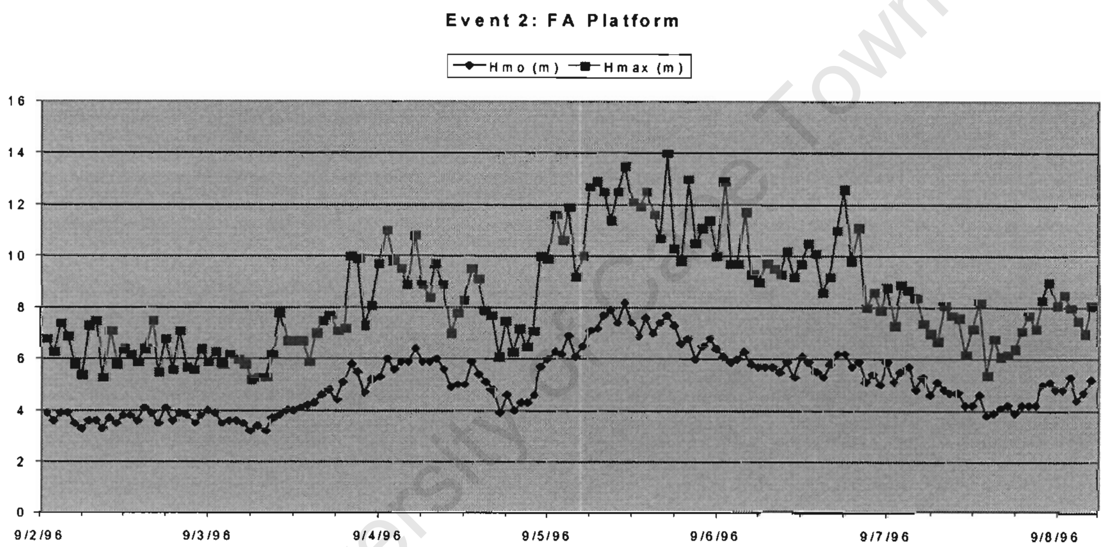


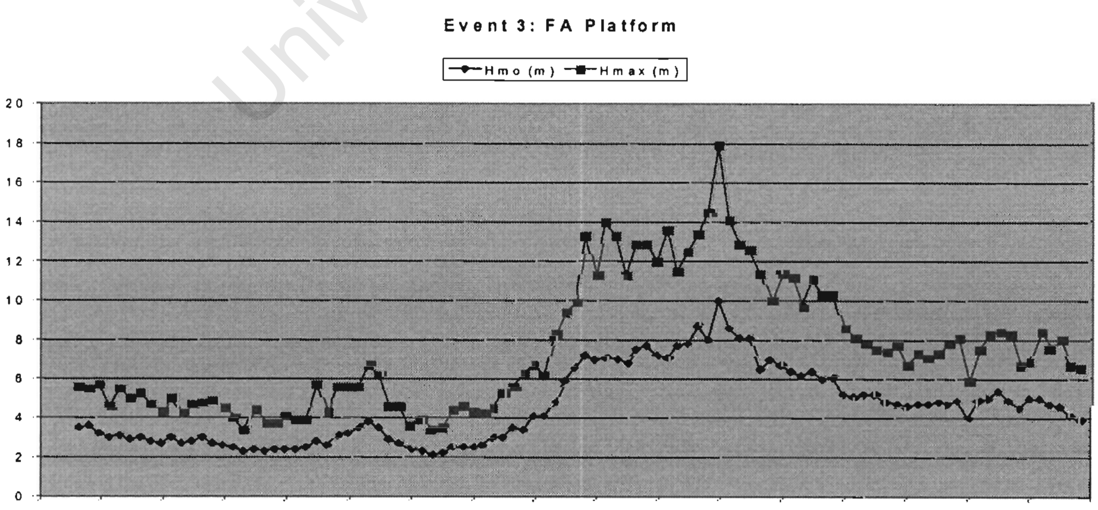
Event 33: Slangkop



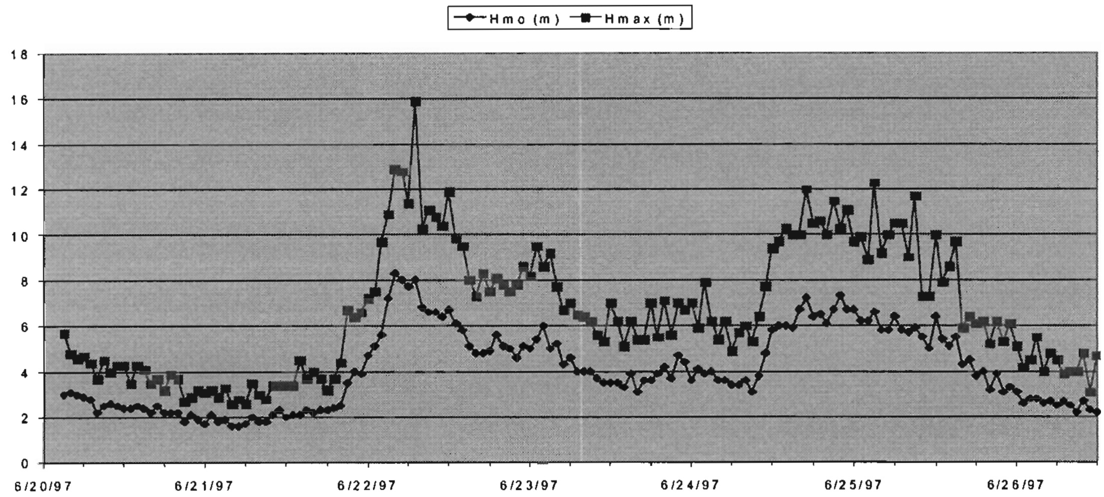
Appendix III: Graphs of events for FA-Platform



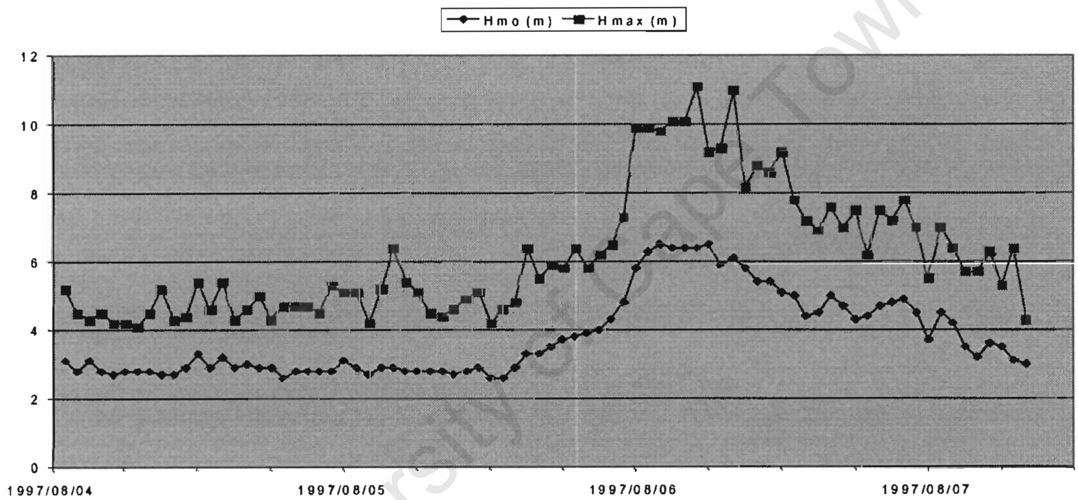




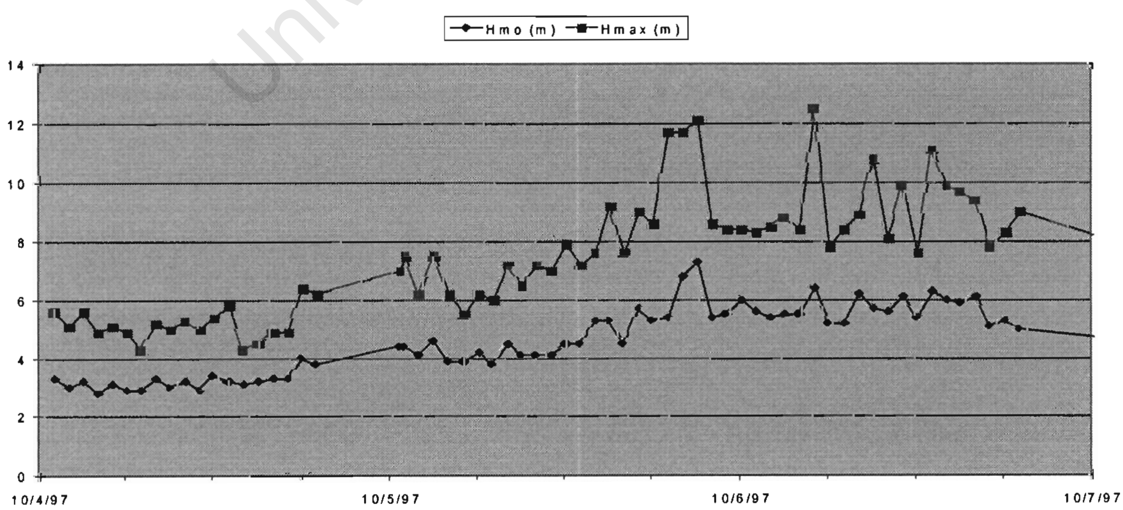
Event 4 + 5: FA Platform

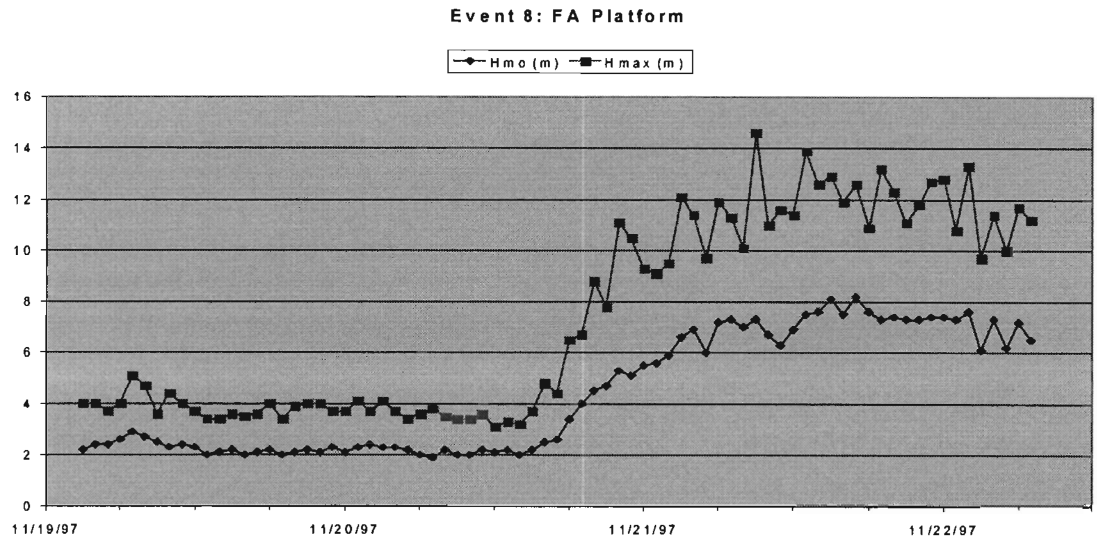


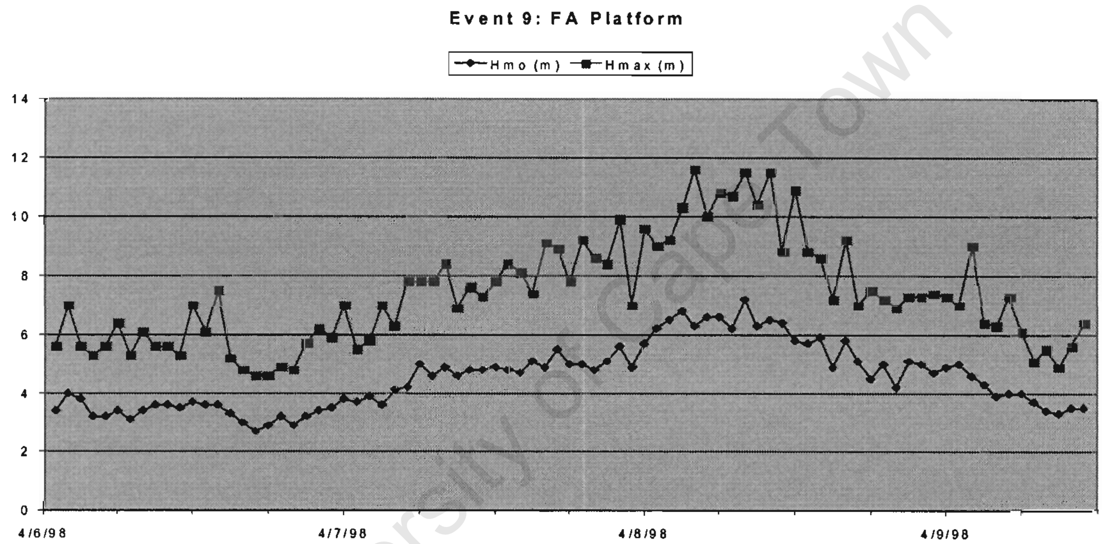
Event 6: FA Platform

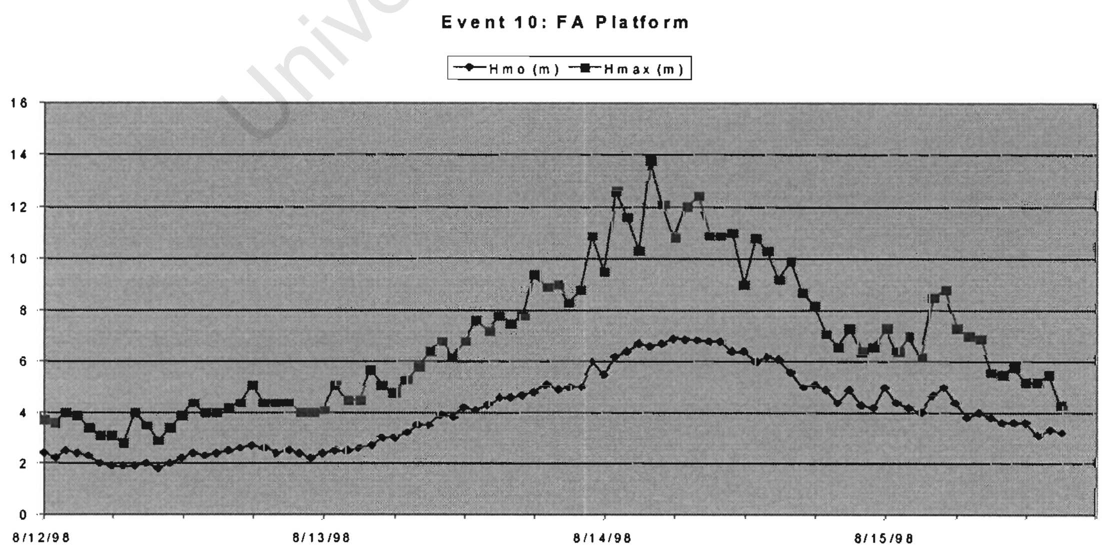


Event 7: FA Platform

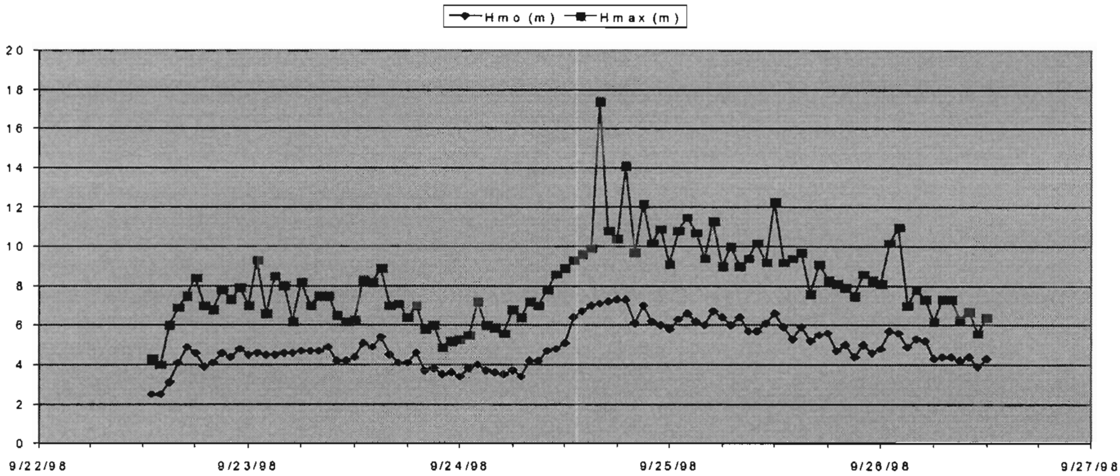



Event 8: FA Platform
Hmo (m)
Hmax (m)
16
14
12
10
8
6
4
2
0
11/19/97
11/20/97
11/21/97
11/22/97

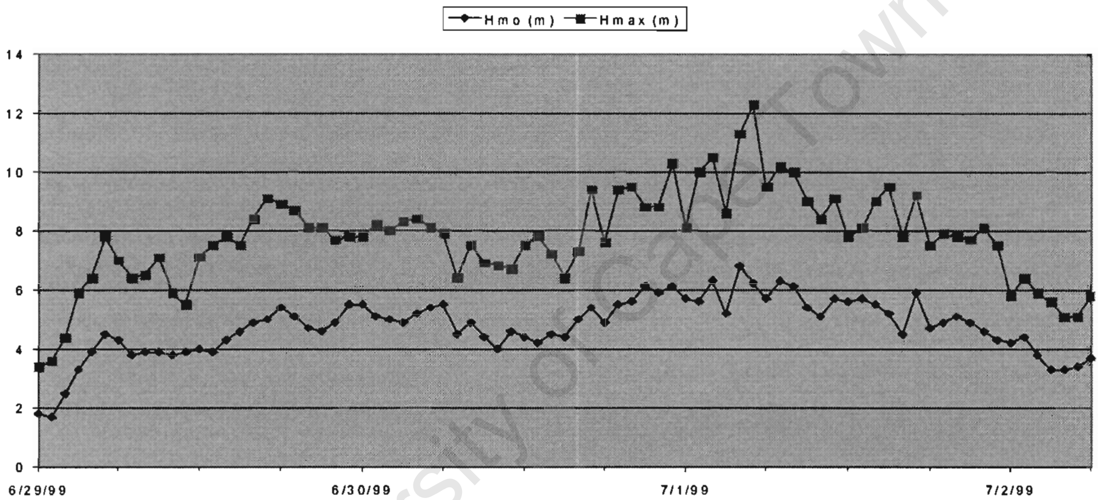

Event 9: FA Platform
Hmo (m)
Hmax (m)
14
12
10
8
6
4
2
0
4/6/98
4/7/98
4/8/98
4/9/98


Event 10: FA Platform
Hmo (m)
Hmax (m)
16
14
12
10
8
6
4
2
0
8/12/98
8/13/98
8/14/98
8/15/98

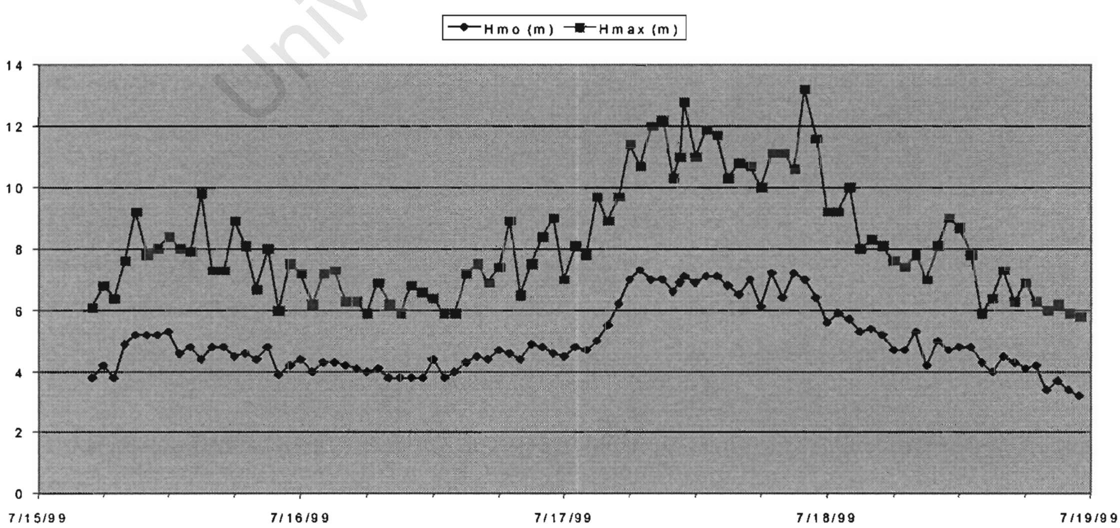
Event 11: FA Platform

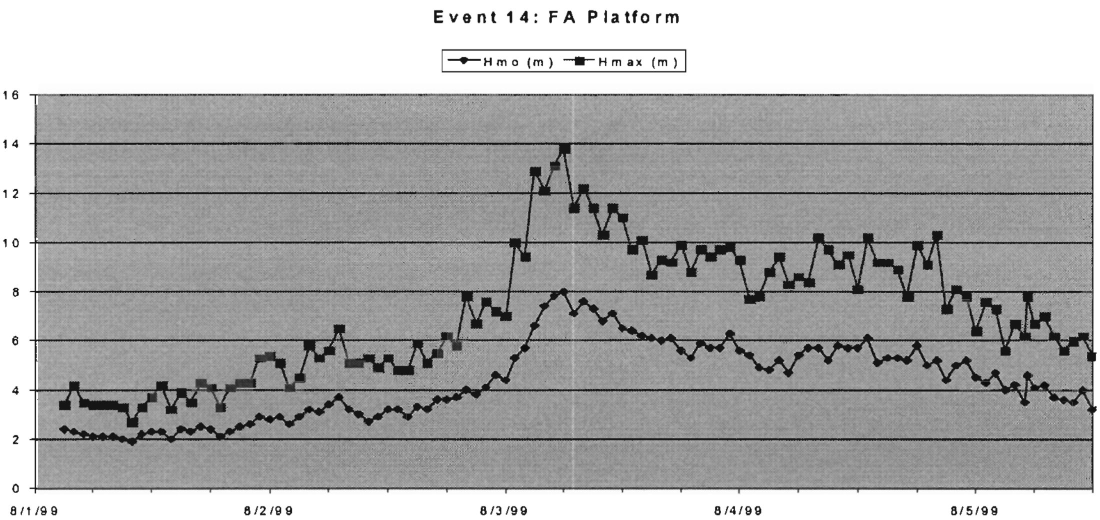


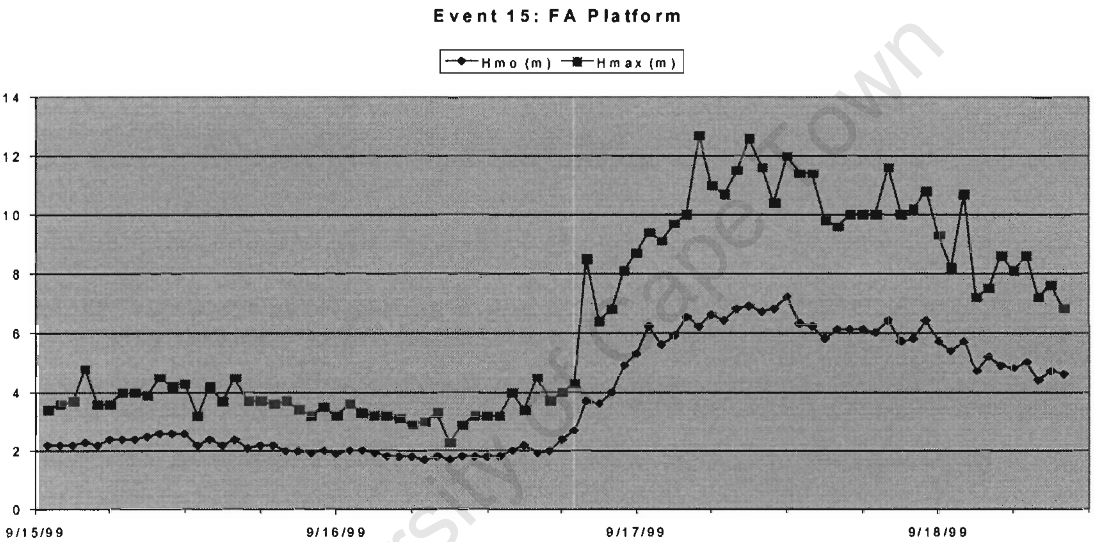
Event 12: FA Platform

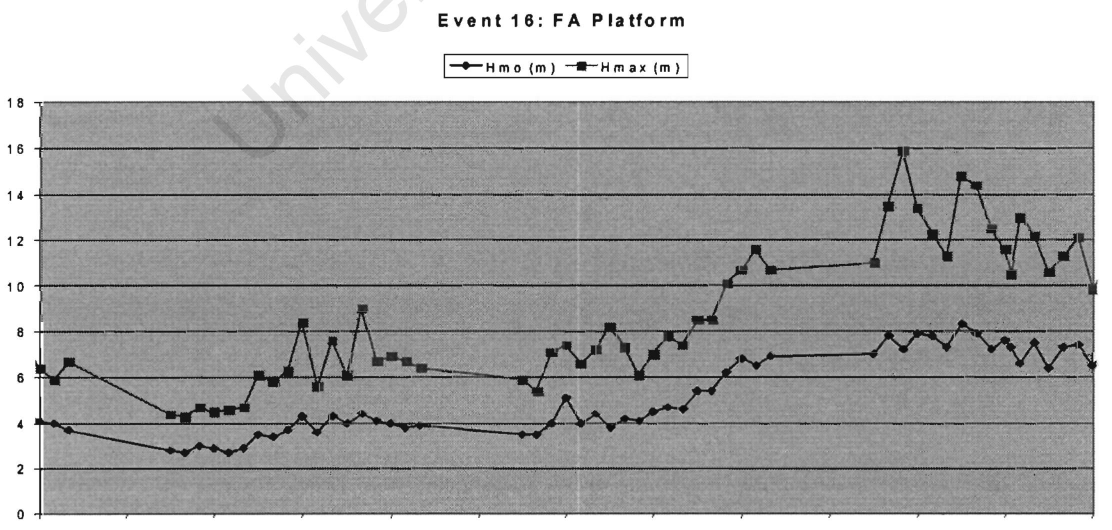


Event 13: FA Platform

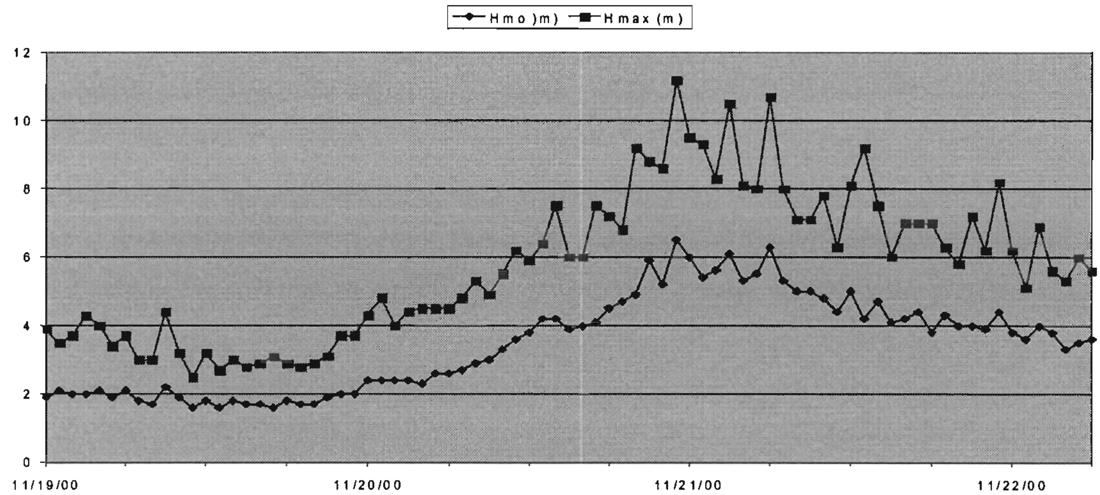



Event 14: FA Platform
Hmo (m)
Hmax (m)
16
14
12
10
8
6
4
2
0
8/1/99
8/2/99
8/3/99
8/4/99
8/5/99

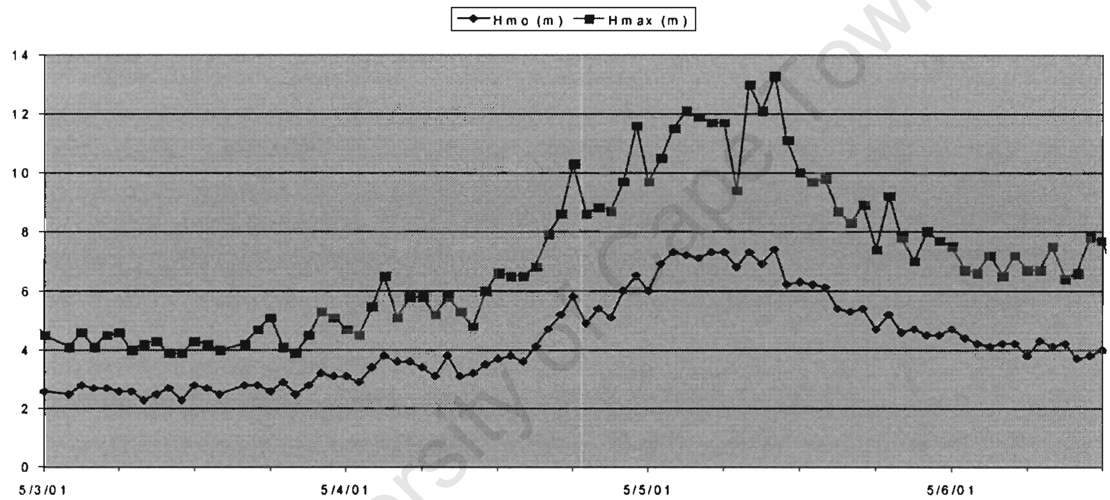

Event 15: FA Platform
Hmo (m)
Hmax (m)
14
12
10
8
6
4
2
0
9/15/99
9/16/99
9/17/99
9/18/99


Event 16: FA Platform
Hmo (m)
Hmax (m)
18
16
14
12
10
8
6
4
2
0
7/16/00
7/17/00
7/18/00
7/19/00

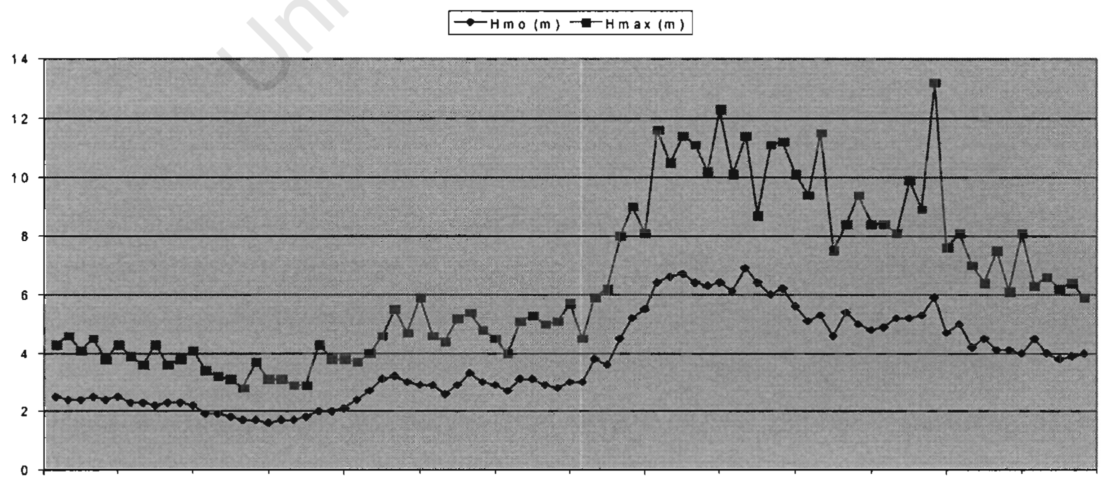
Event 17: FA Platform



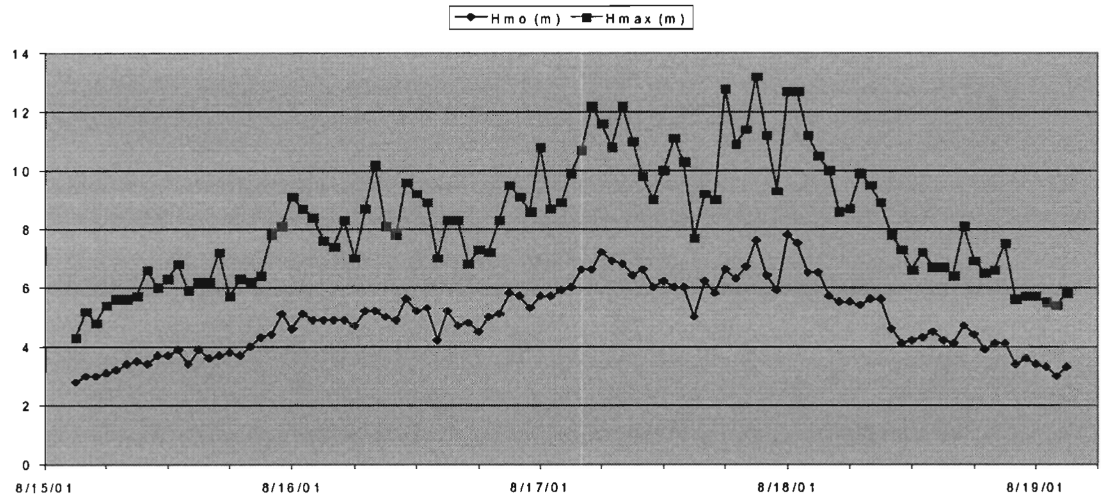
Event 18: FA Platform



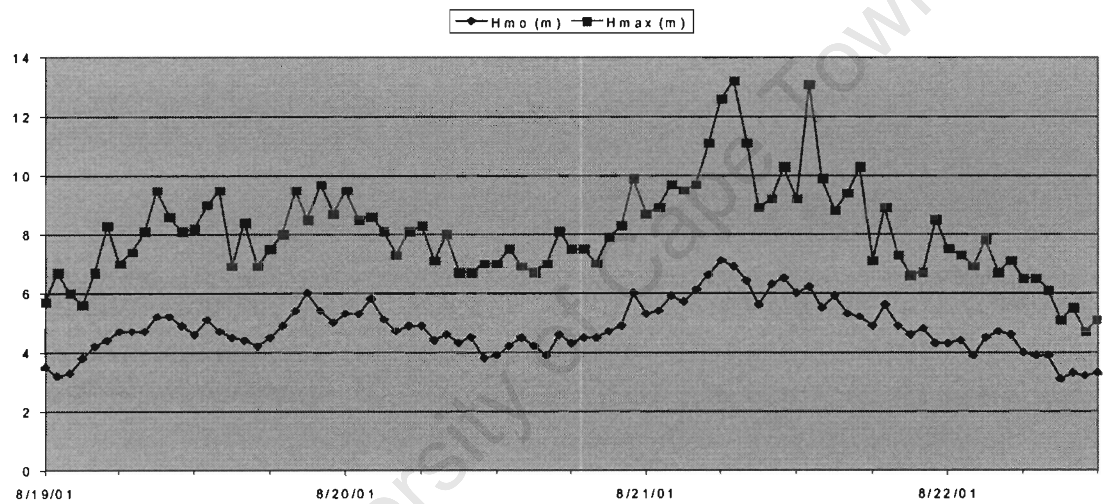
Event 19: FA Platform



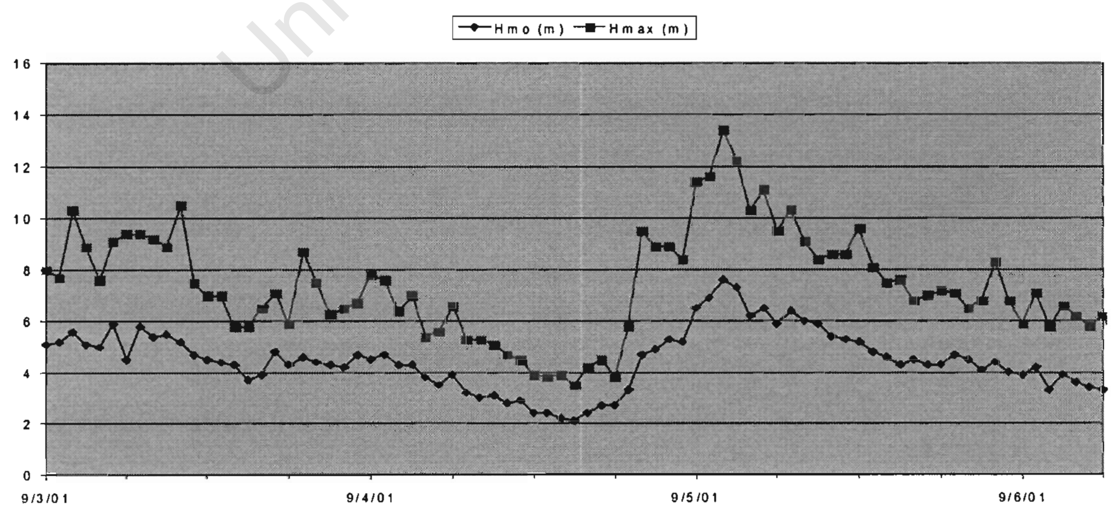
Event 20: FA Platform

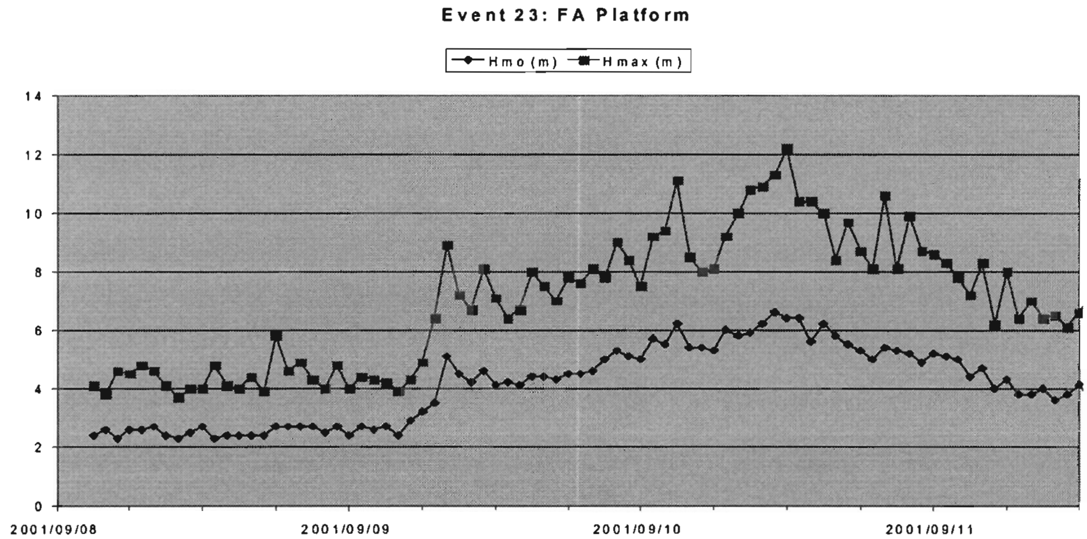


Event 21: FA Platform

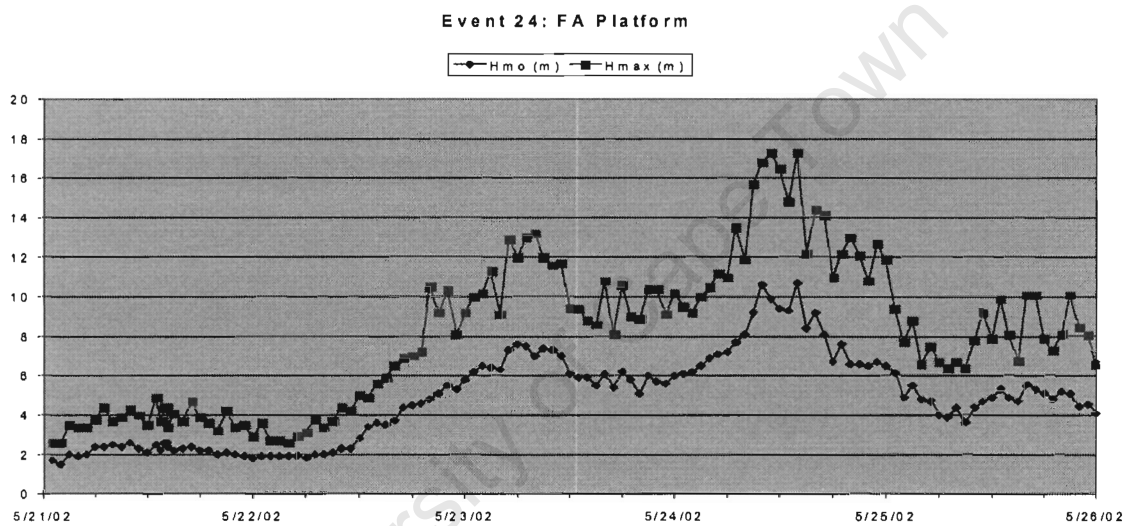


Event 22: FA Platform

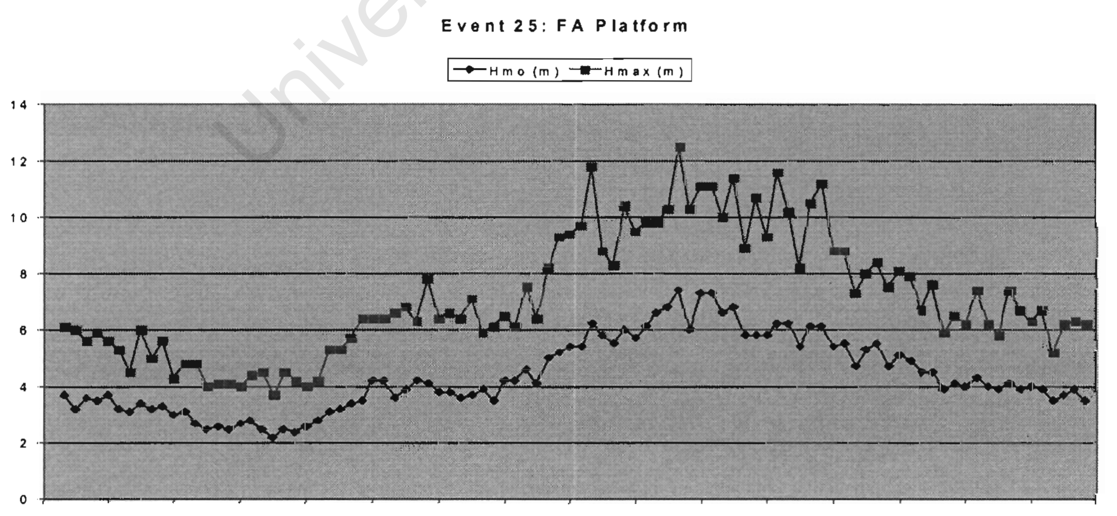




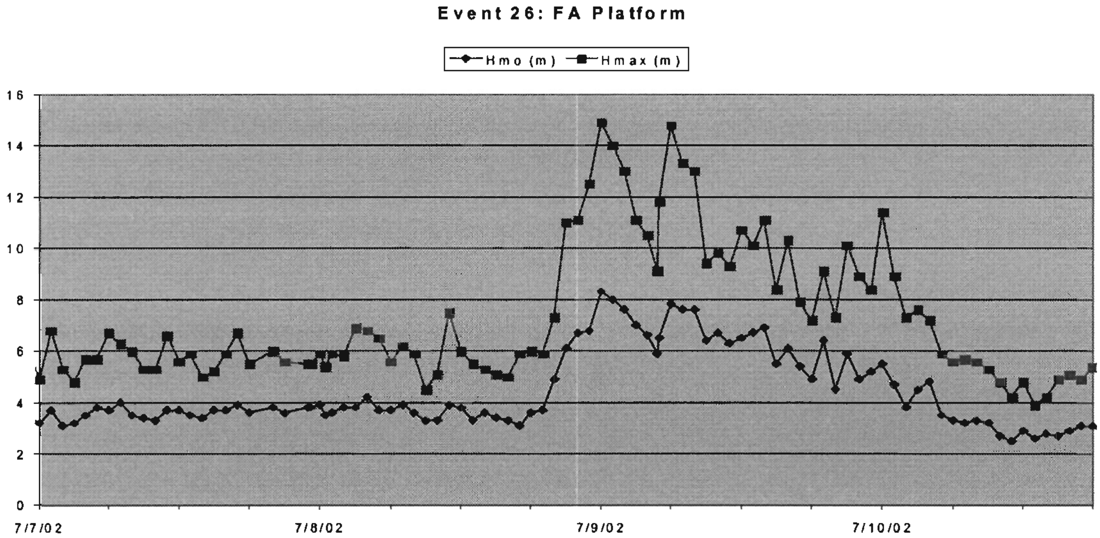
Event 23: FA Platform
Hmo (m)
Hmax (m)
14
12
10
8
6
4
2
0
2001/09/08
2001/09/09
2001/09/10
2001/09/11

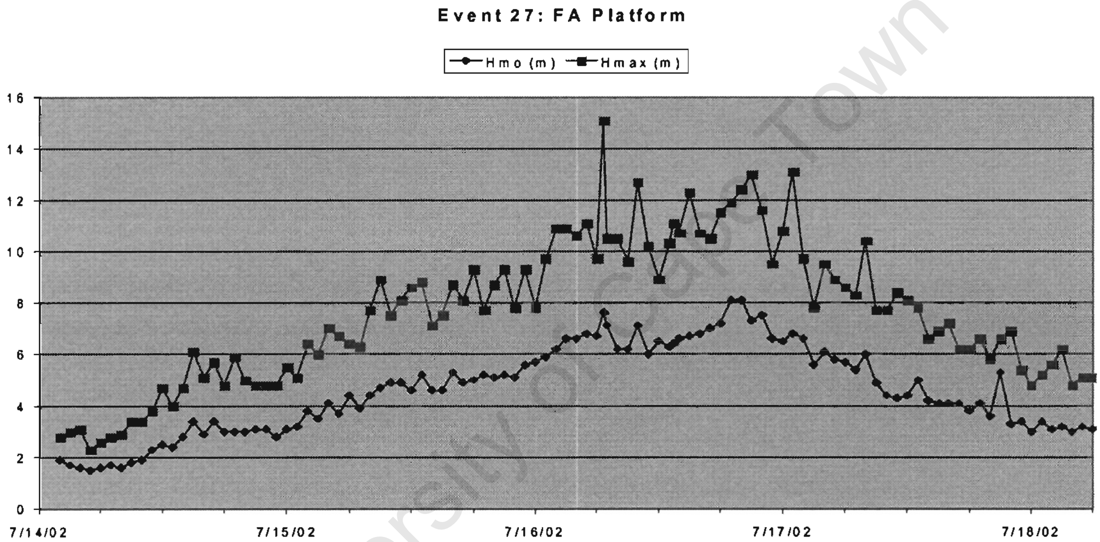


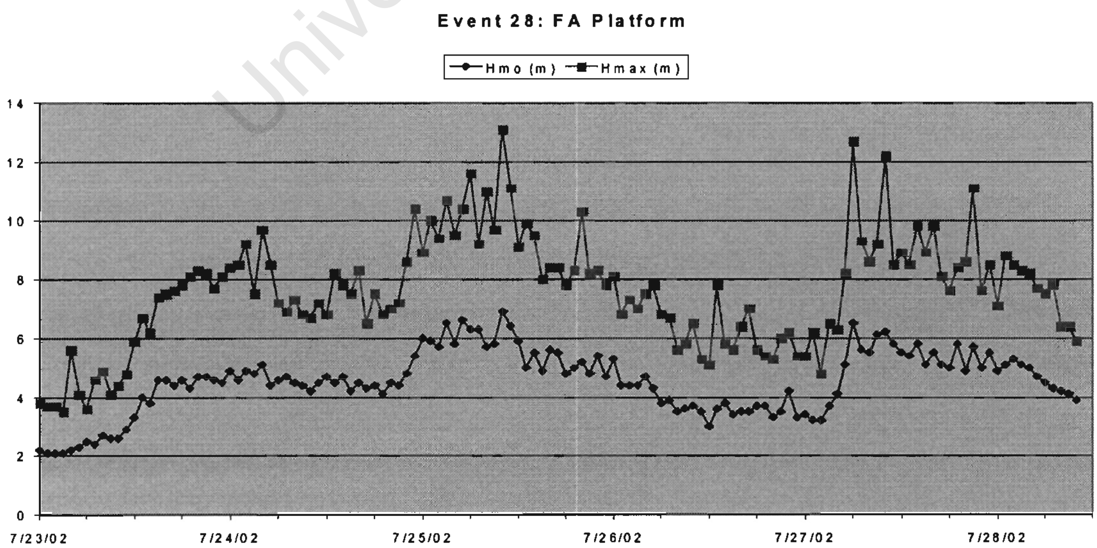
Event 24: FA Platform
Hmo (m)
Hmax (m)
20
18
16
14
12
10
8
6
4
2
0
5/21/02
5/22/02
5/23/02
5/24/02
5/25/02
5/26/02



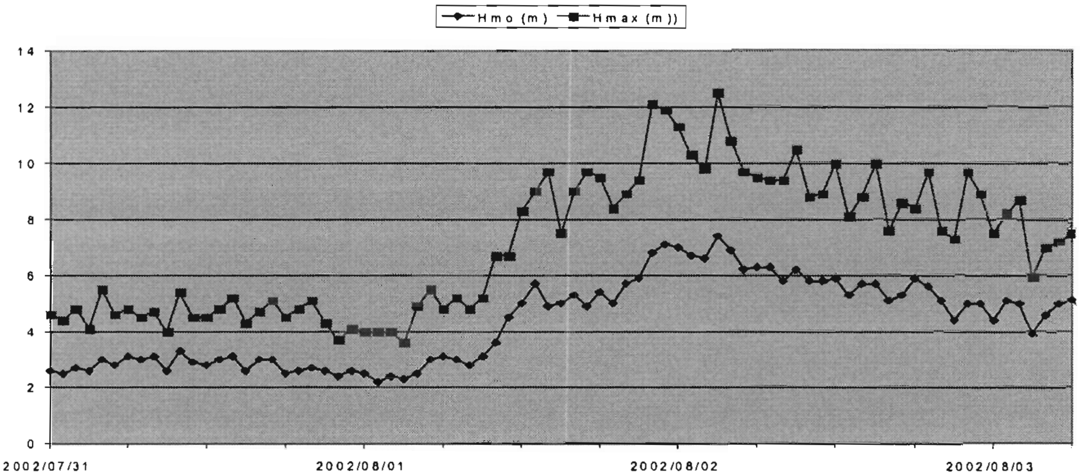
Event 25: FA Platform
Hmo (m)
Hmax (m)
14
12
10
8
6
4
2
0
6/16/02
6/17/02
6/18/02
6/19/02
6/20/02


Event 26: FA Platform
Hmo (m)
Hmax (m)
0
2
4
6
8
10
12
14
16
7/7/02
7/8/02
7/9/02
7/10/02

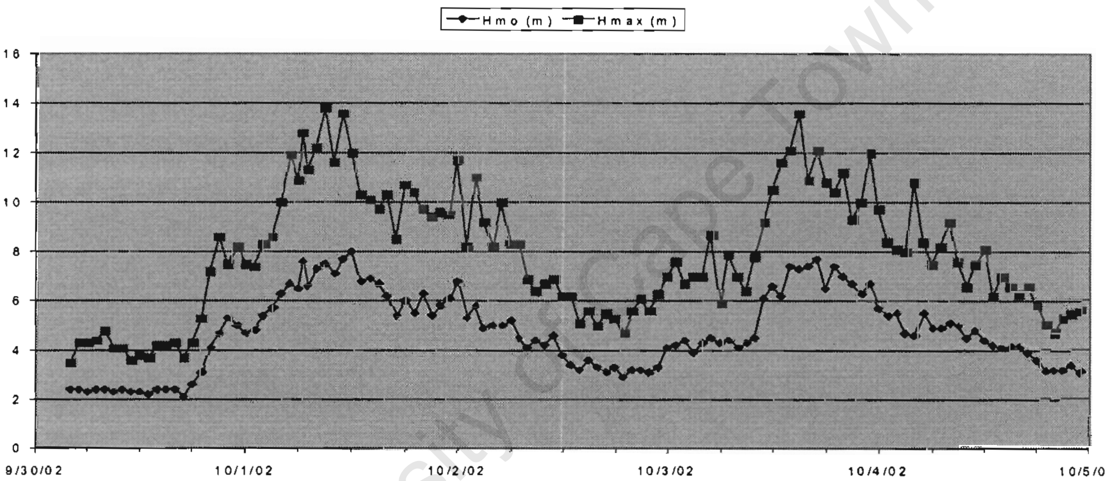

Event 27: FA Platform
Hmo (m)
Hmax (m)
0
2
4
6
8
10
12
14
16
7/14/02
7/15/02
7/16/02
7/17/02
7/18/02


Event 28: FA Platform
Hmo (m)
Hmax (m)
0
2
4
6
8
10
12
14
7/23/02
7/24/02
7/25/02
7/26/02
7/27/02
7/28/02

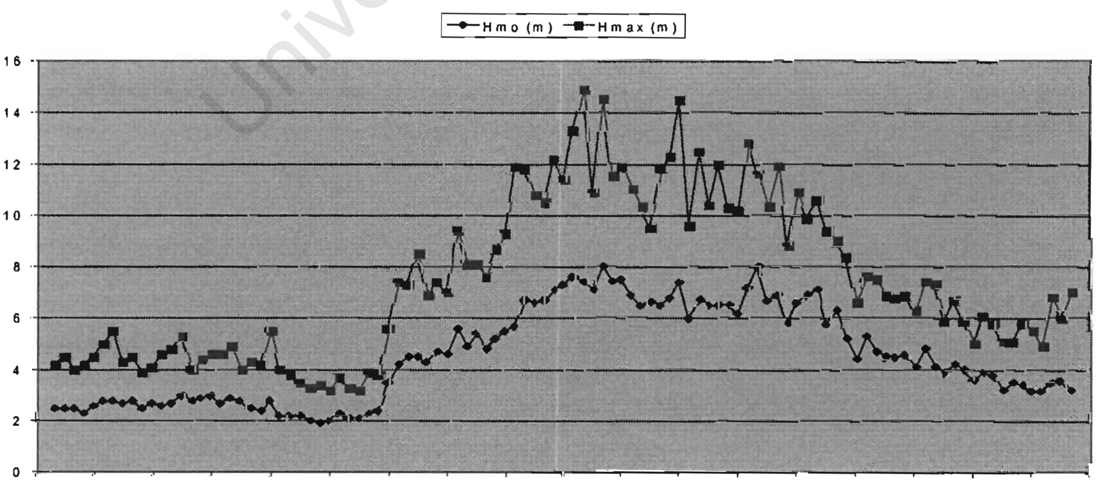
Event 29: FA Platform



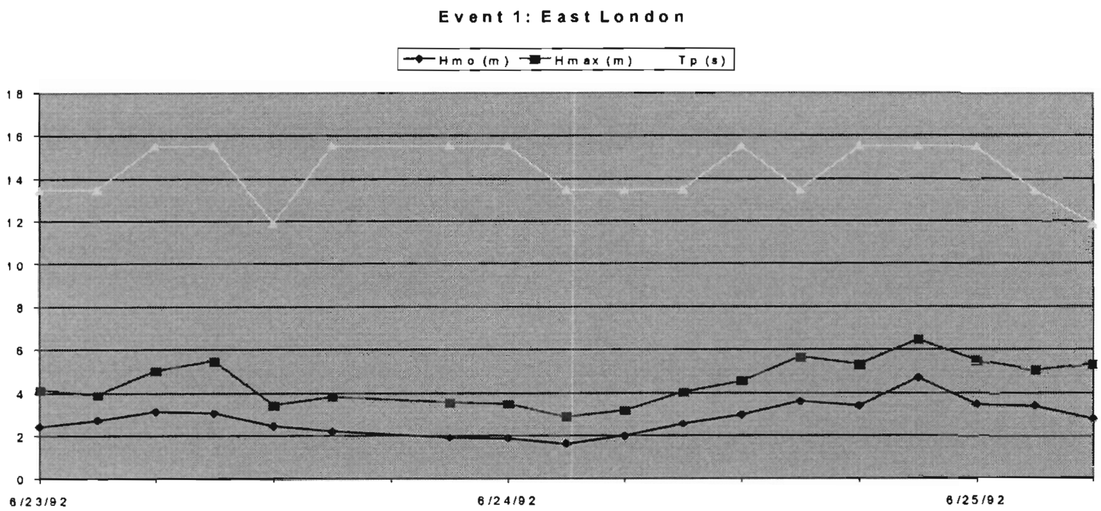
Event 30 + 31: FA Platform

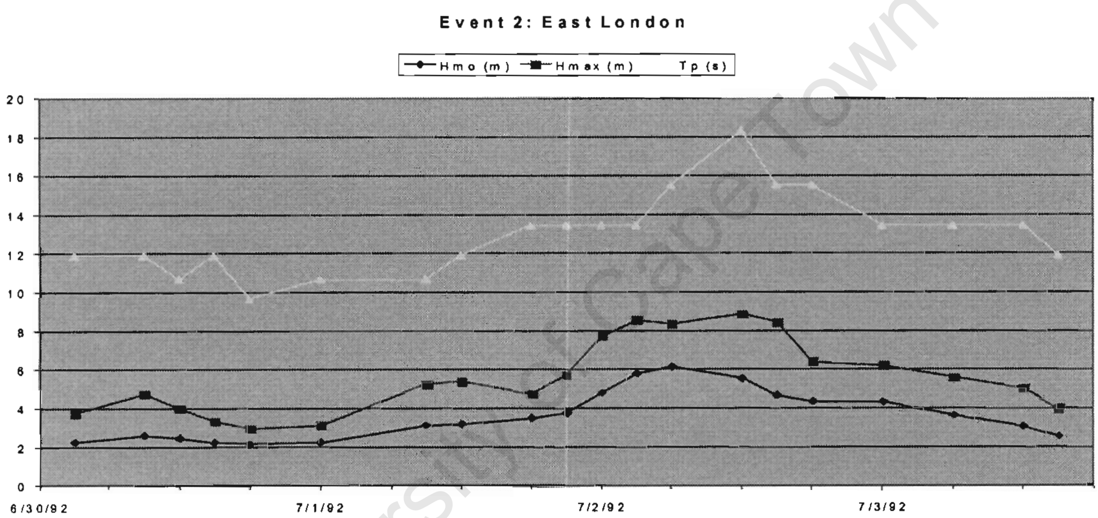


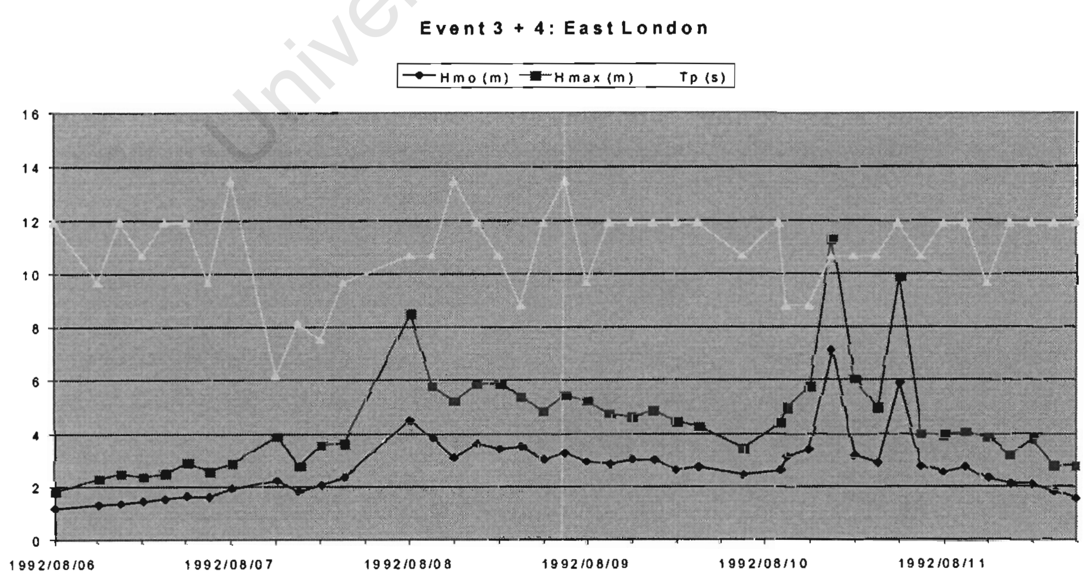
Event 32: FA Platform



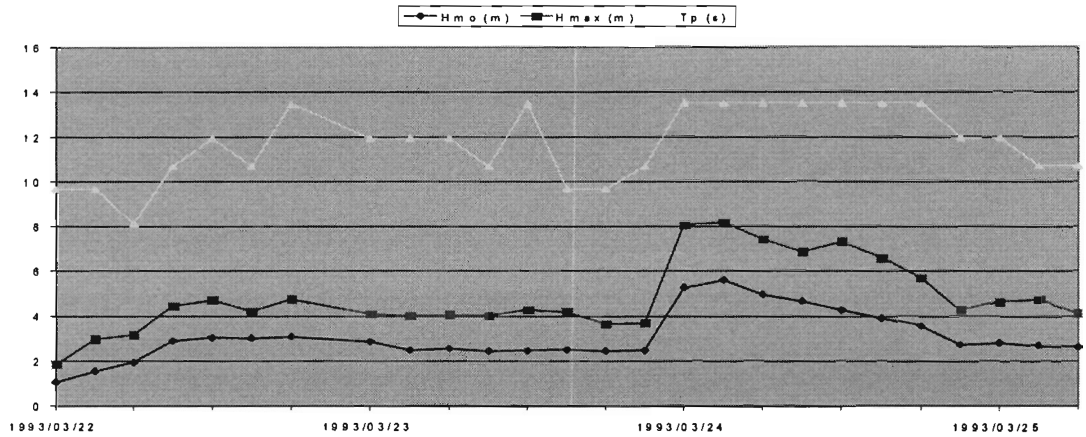
Appendix IV: Graphs of events for East London



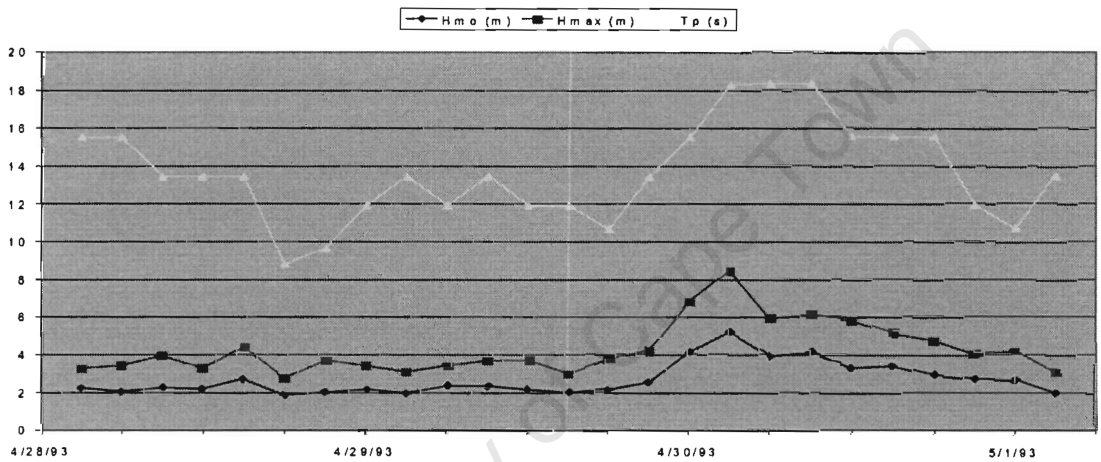




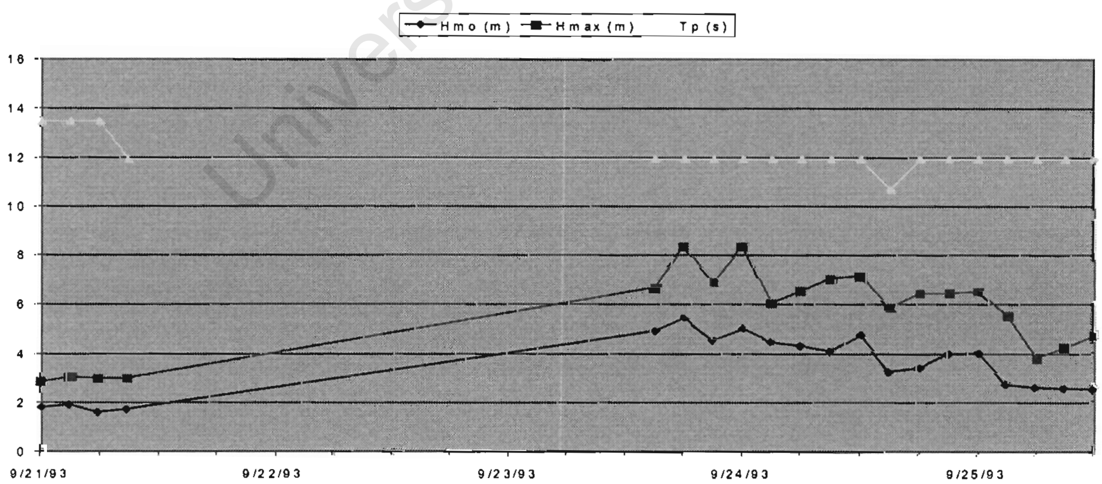
Event 5: East London



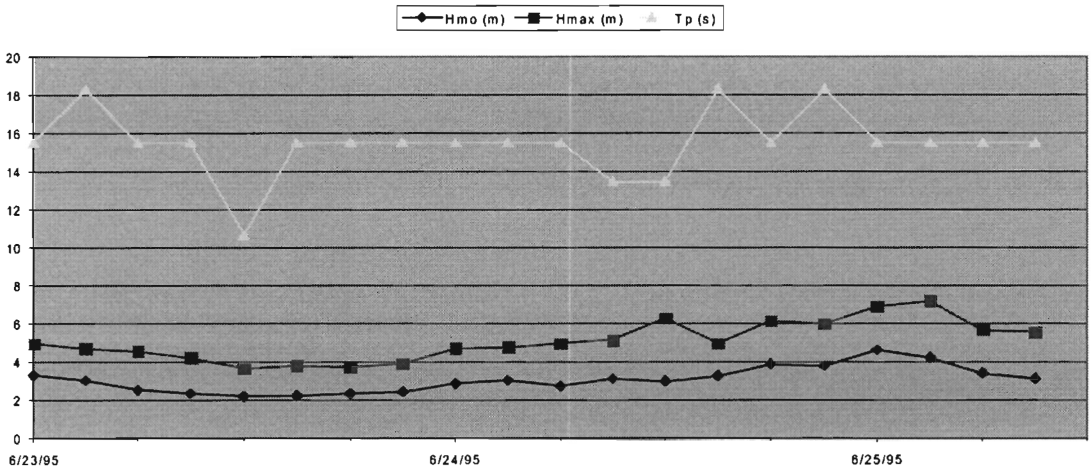
Event 6: East London



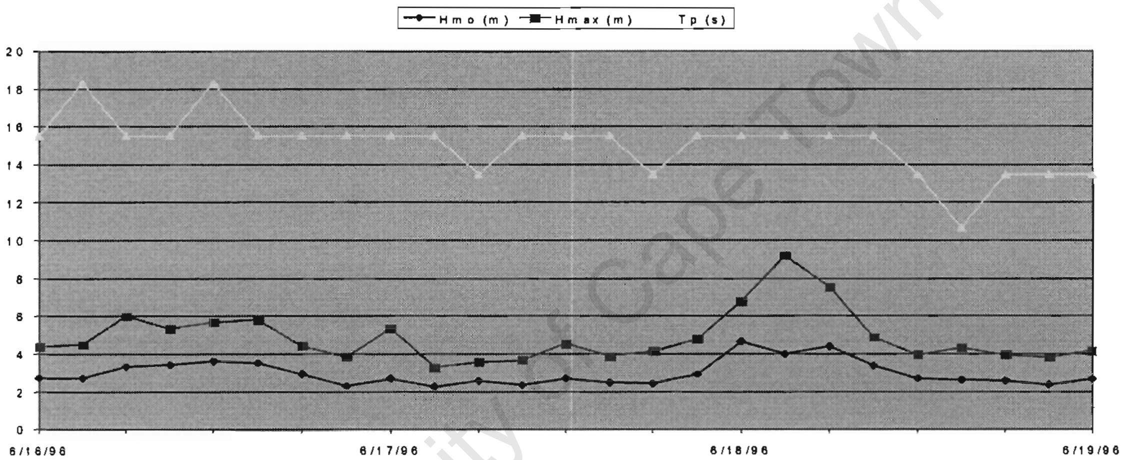
Event 7: East London



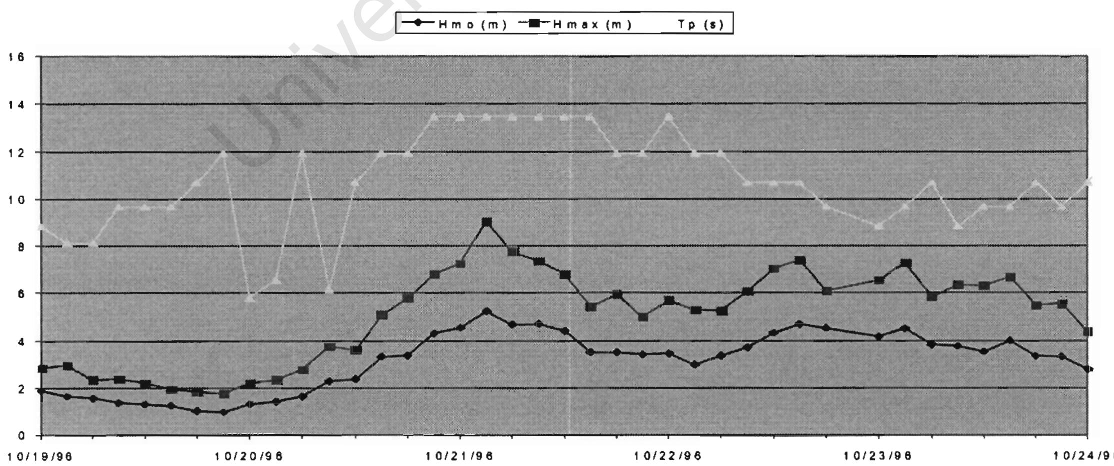
Event 8: East London



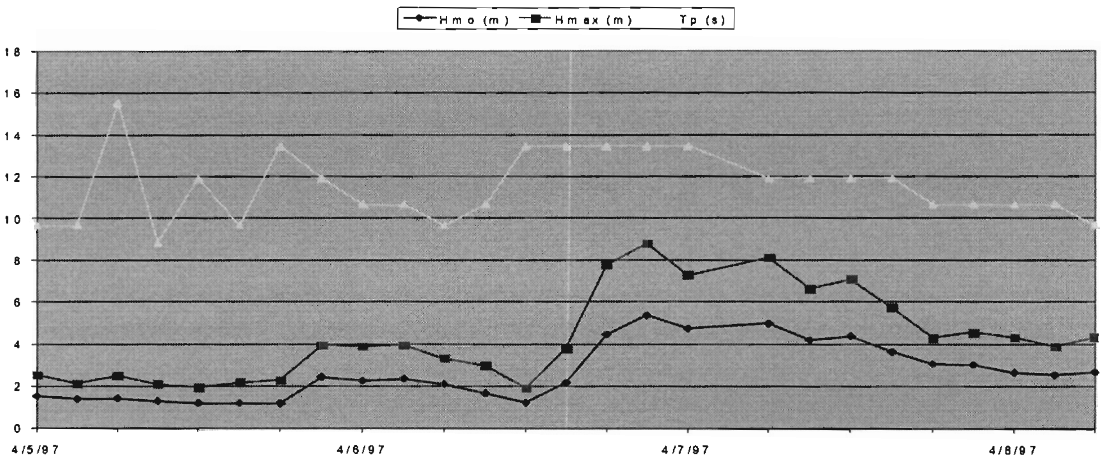
Event 9: East London



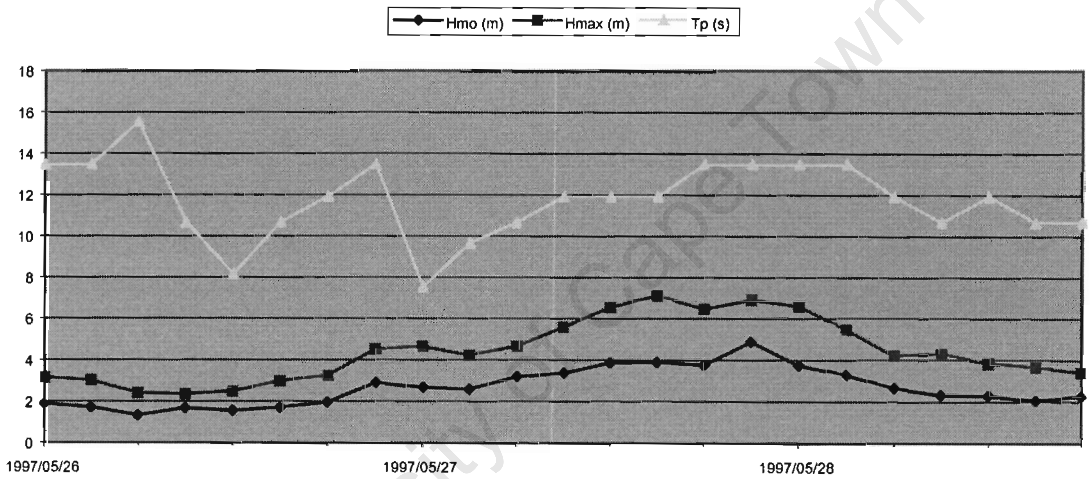
Event 10: East London



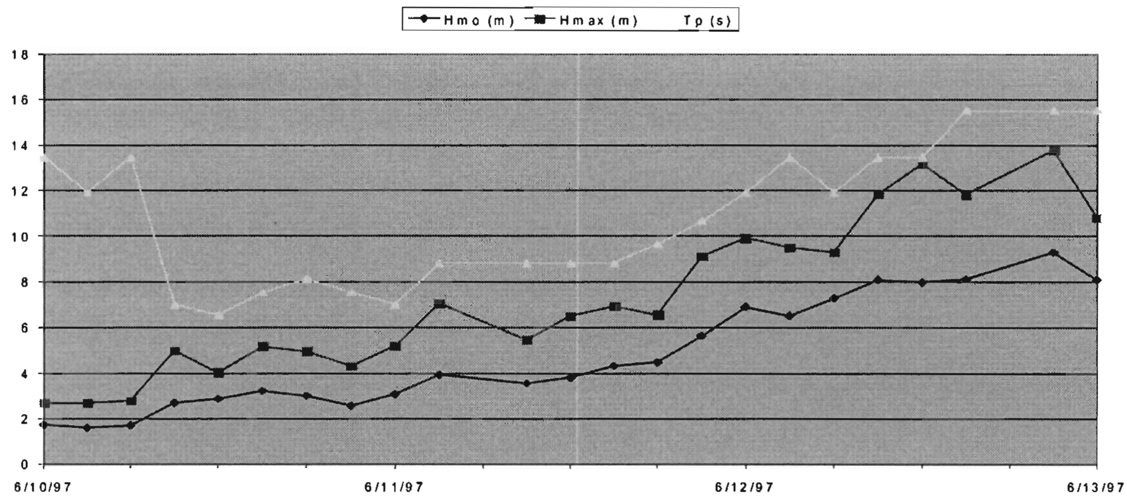
Event 11: East London



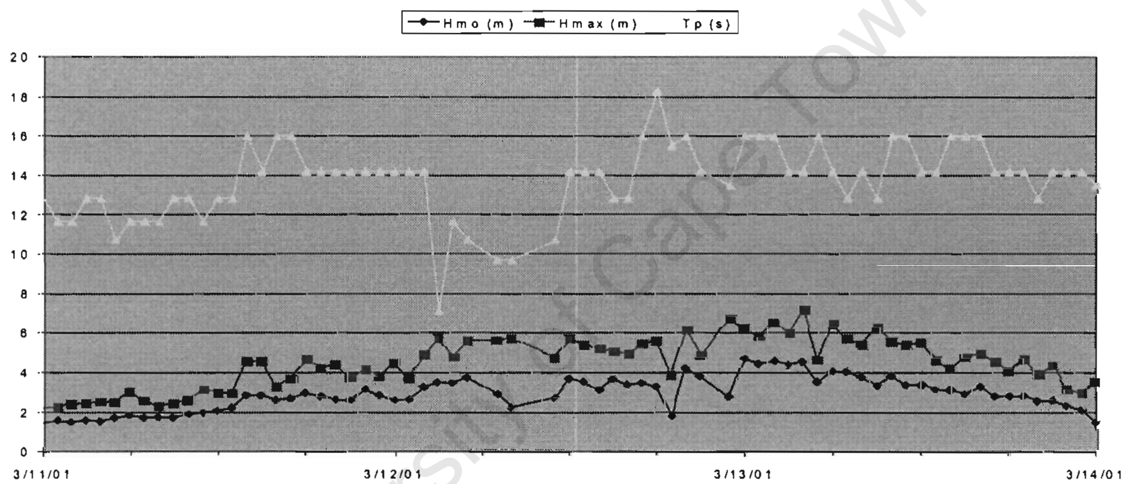
Event 12: East London



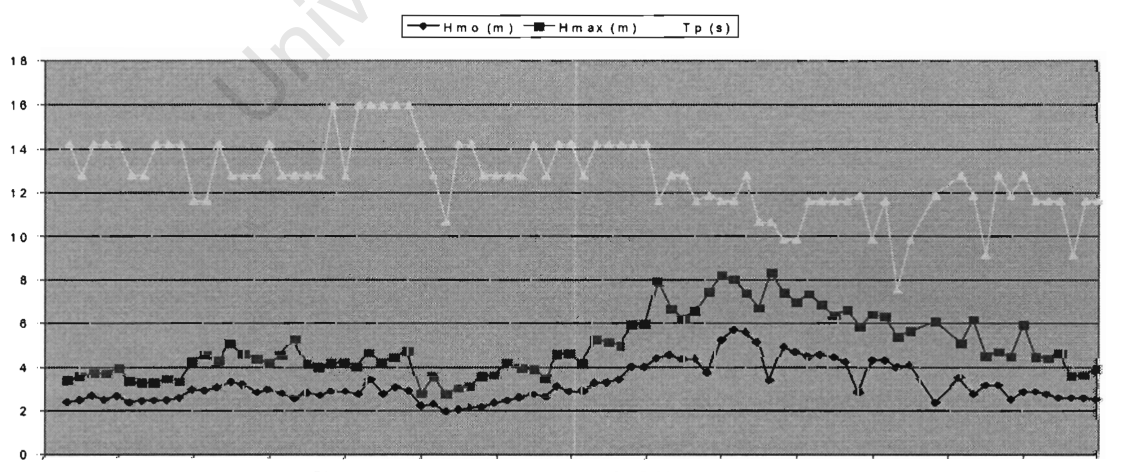
Event 13: East London



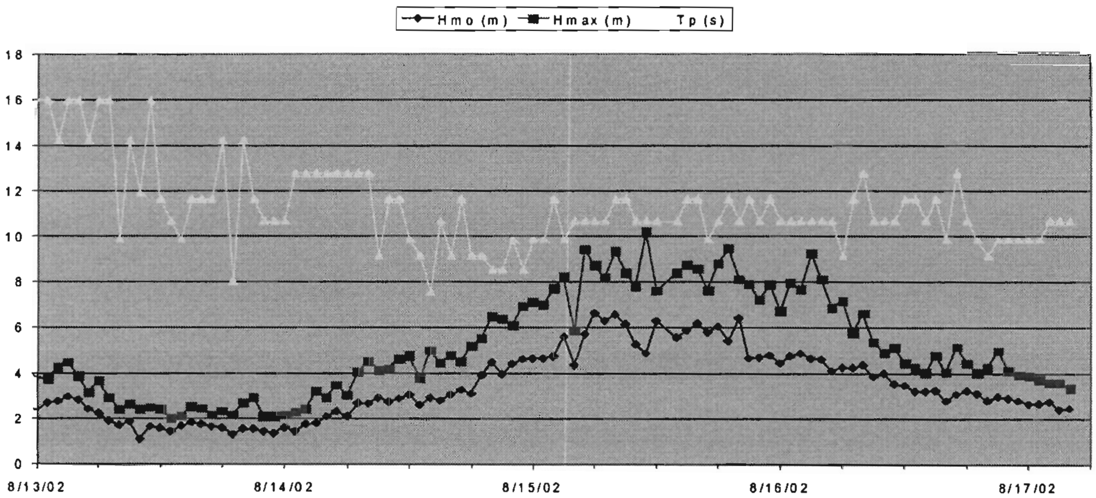
Event 14: East London



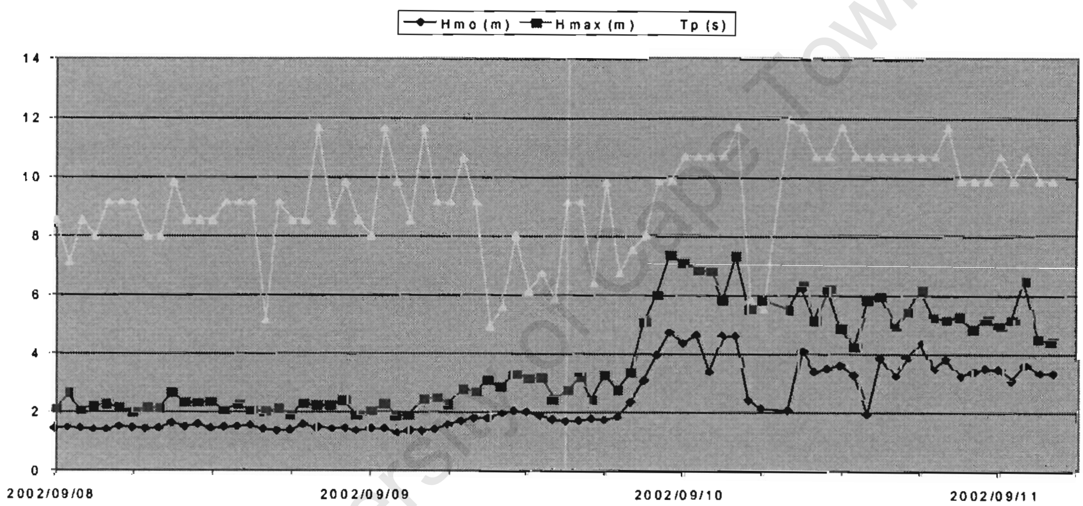
Event 15: East London

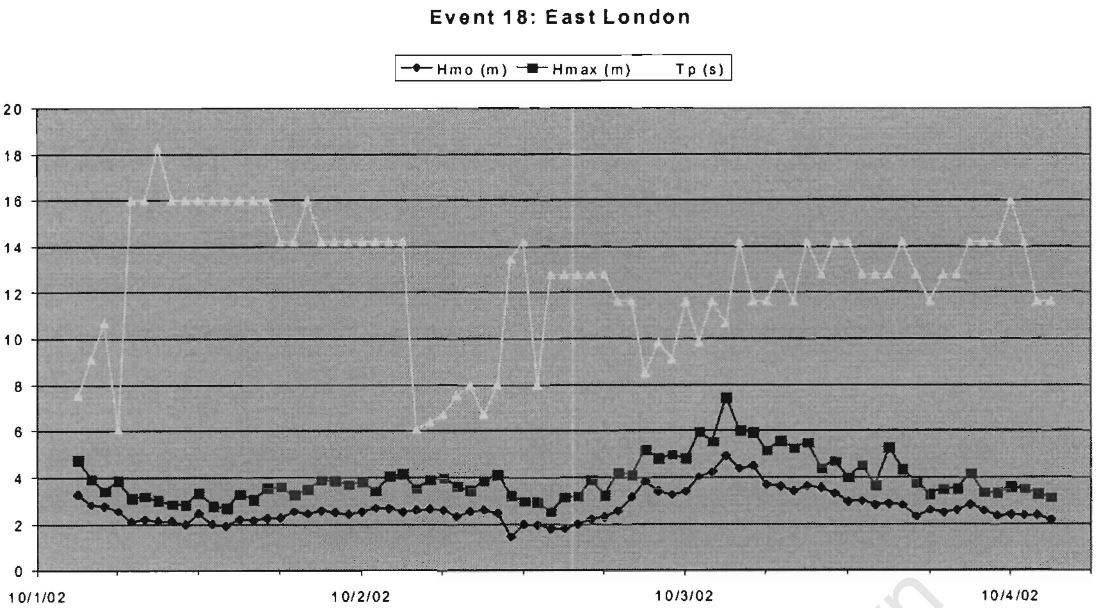


Event 16: East London

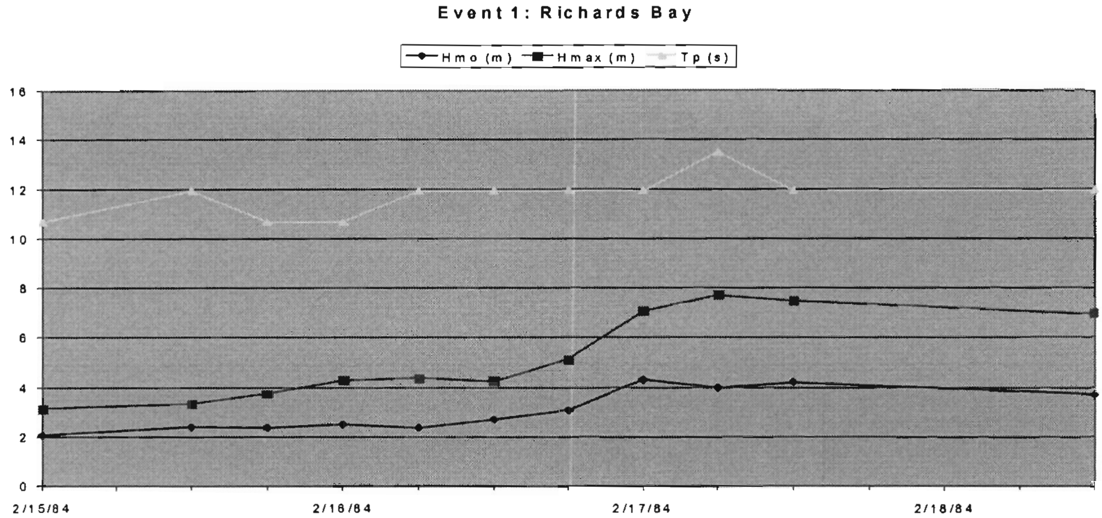


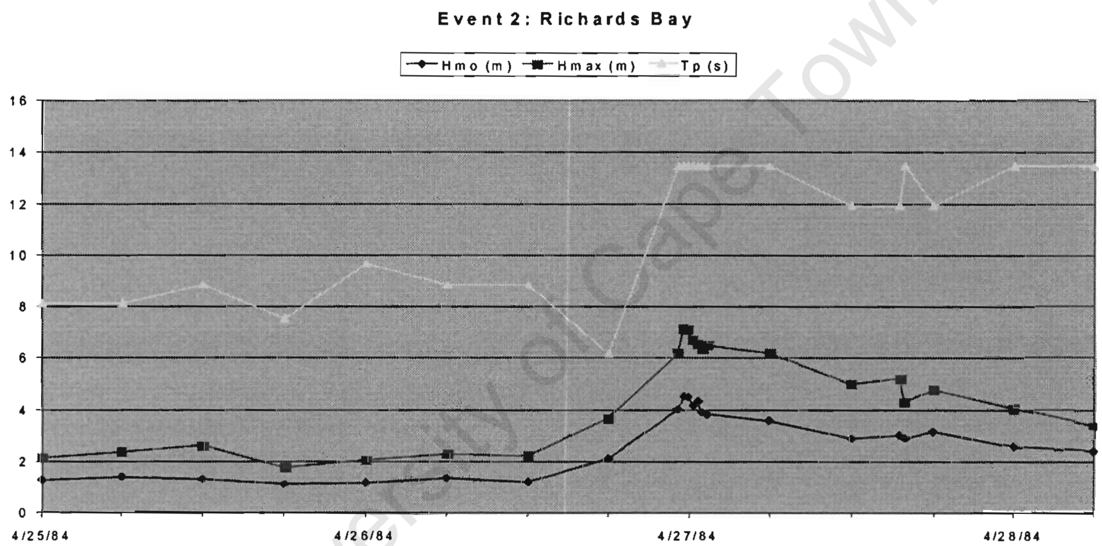
Event 17: East London

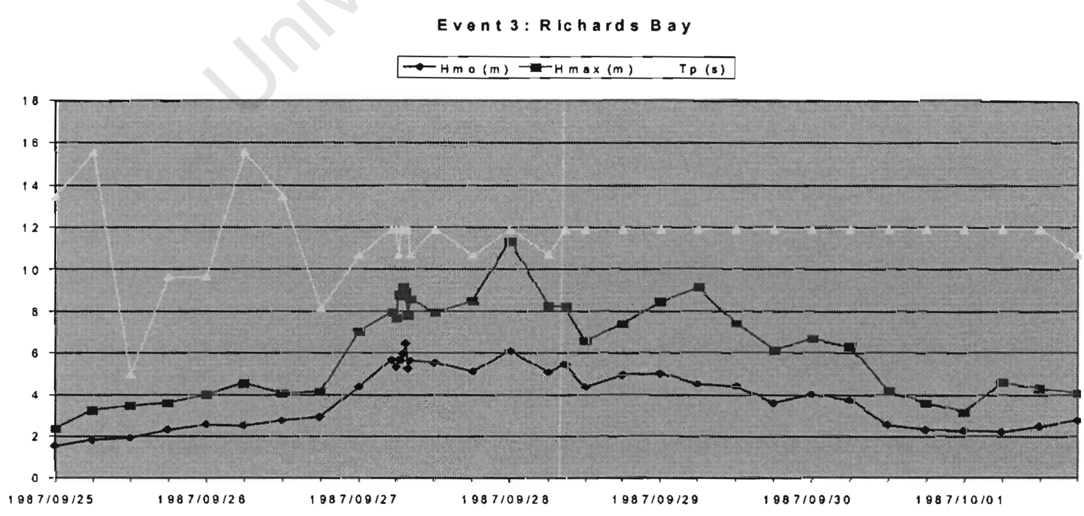



Event 18: East London
Hmo (m)
Hmax (m)
Tp (s)
20
18
16
14
12
10
8
6
4
2
0
10/1/02
10/2/02
10/3/02
10/4/02

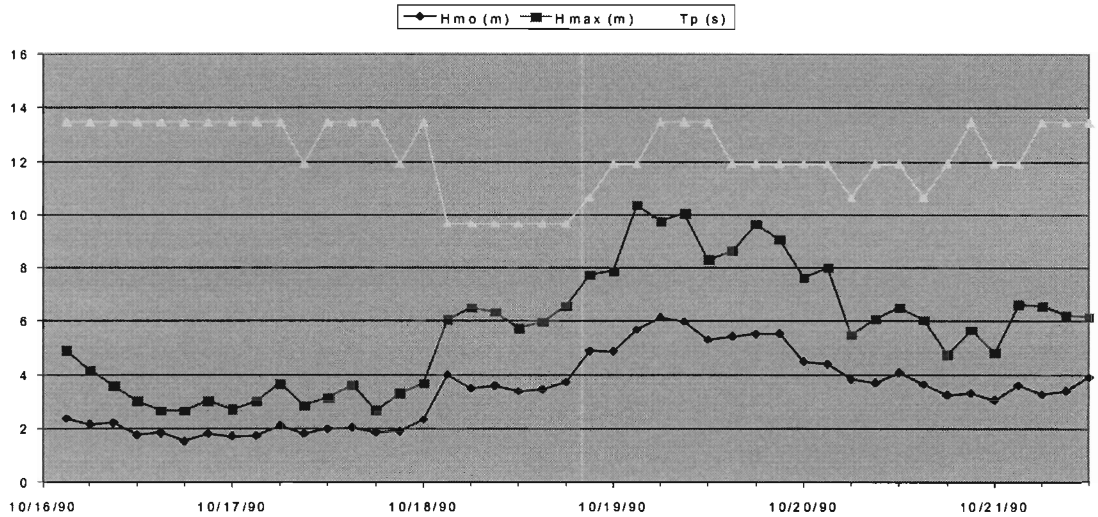
Appendix V: Characteristics of events for Richards Bay



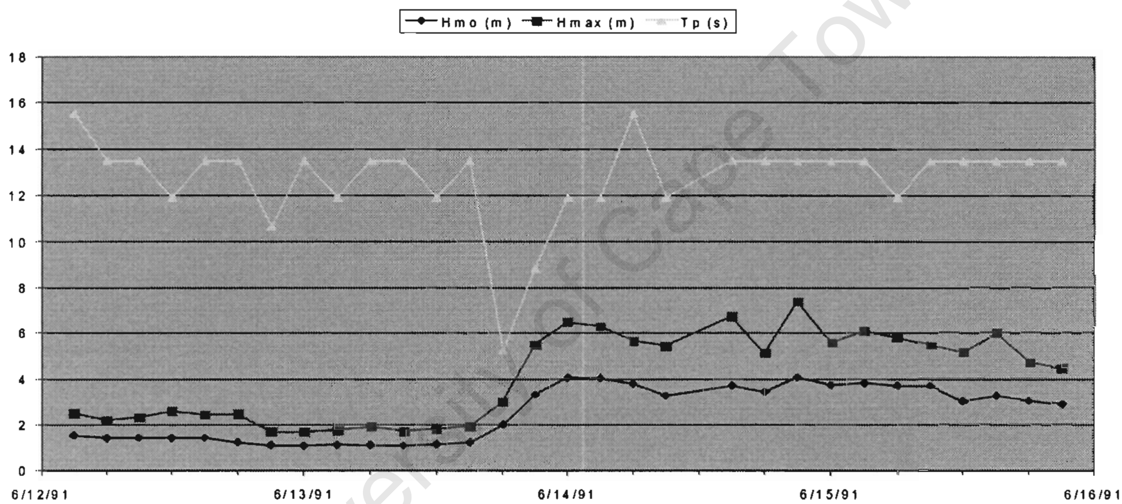




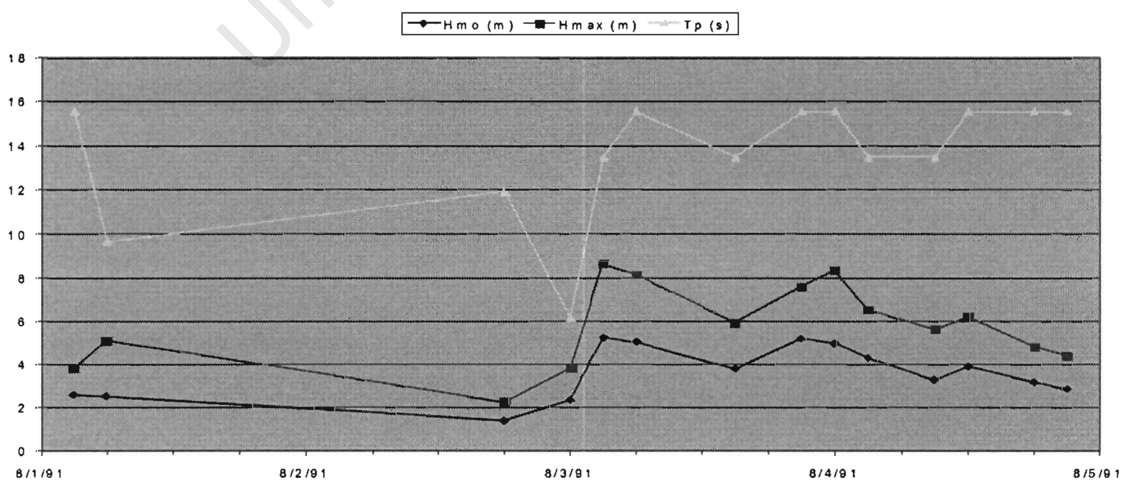
Event 4: Richards Bay



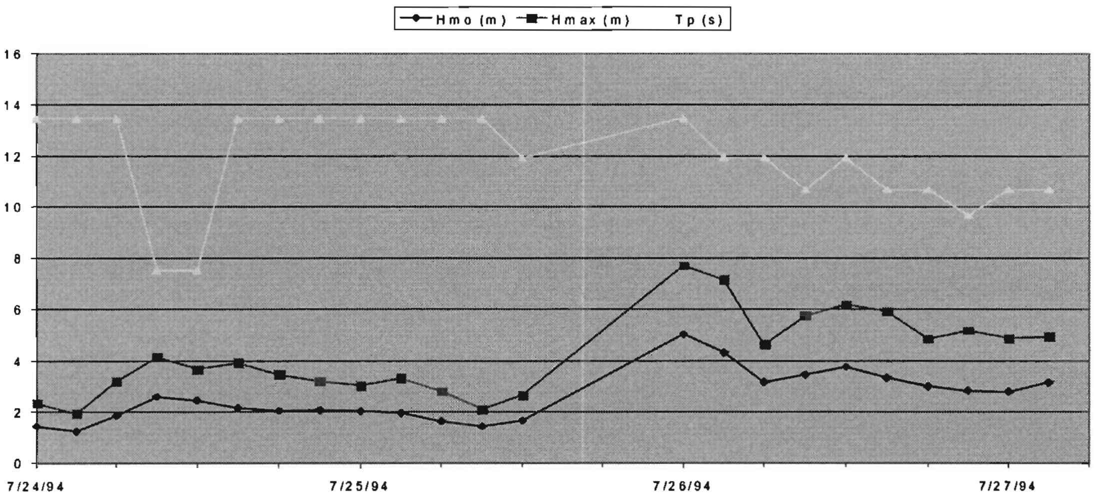
Event 5: Richards Bay



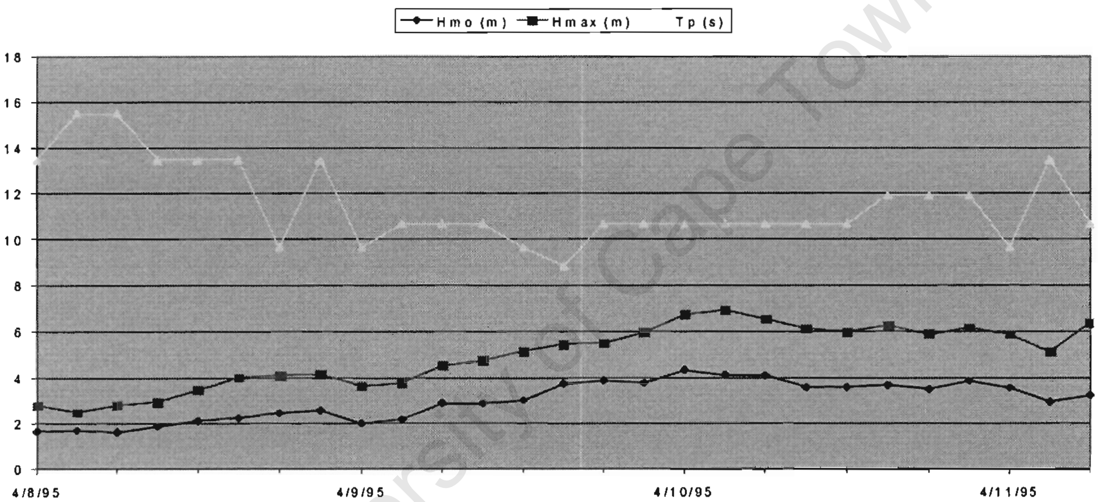
Event 6: Richards Bay



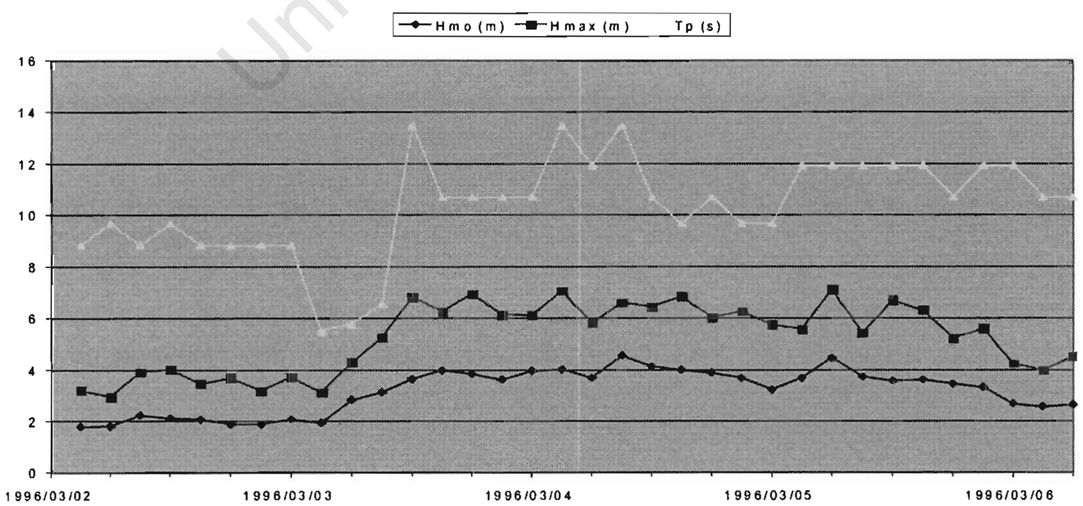
Event 7: Richards Bay



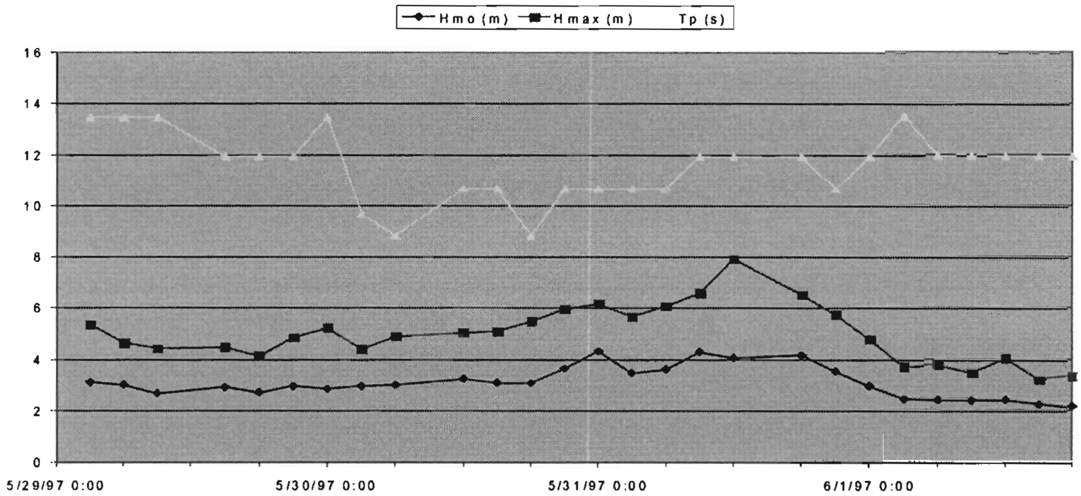
Event 8: Richards Bay



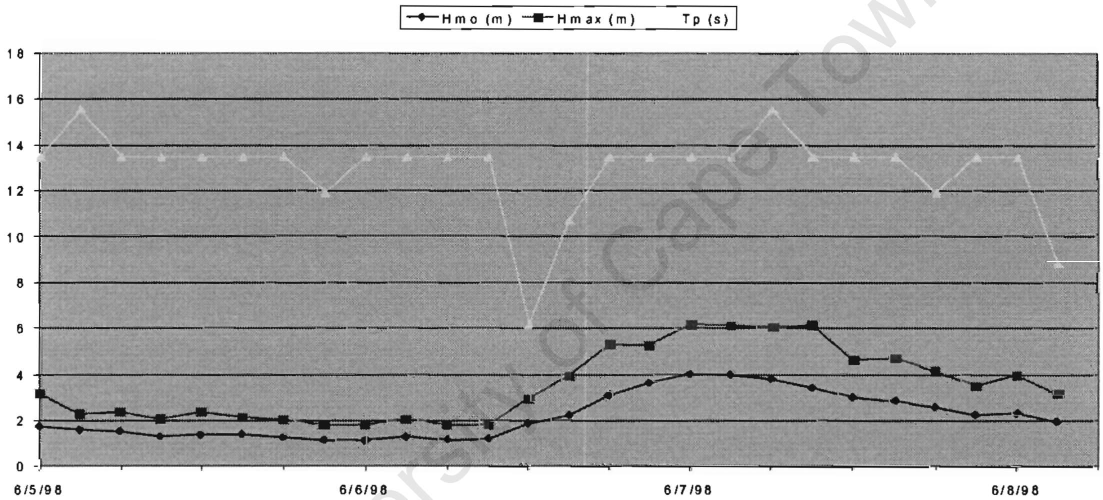
Event 9: Richards Bay



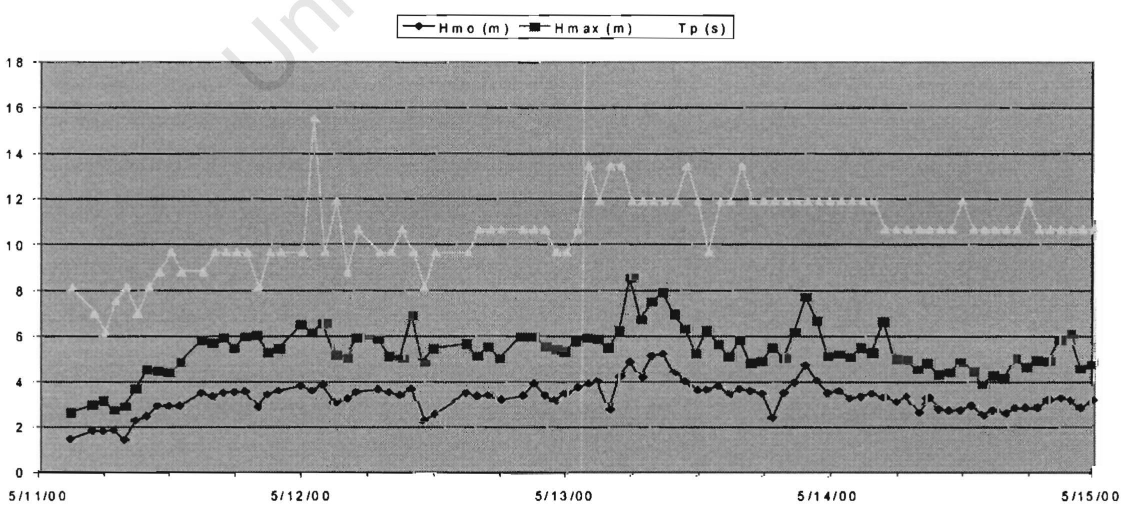
Event 10: Richards Bay



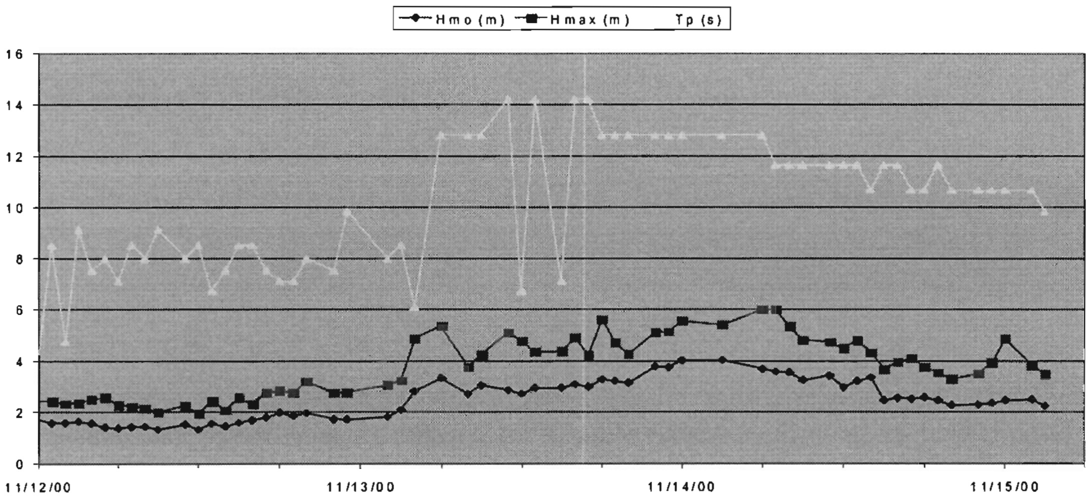
Event 11: Richards Bay



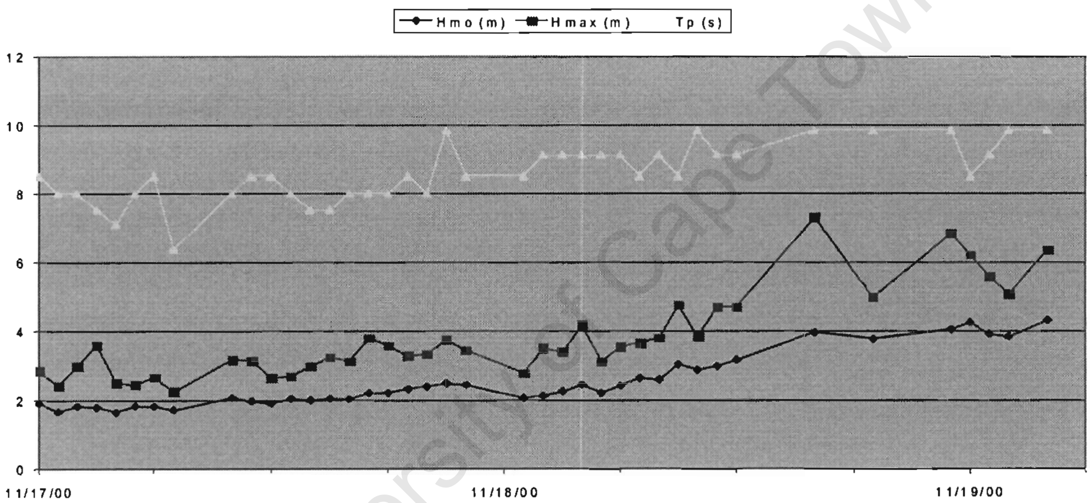
Event 12: Richards Bay



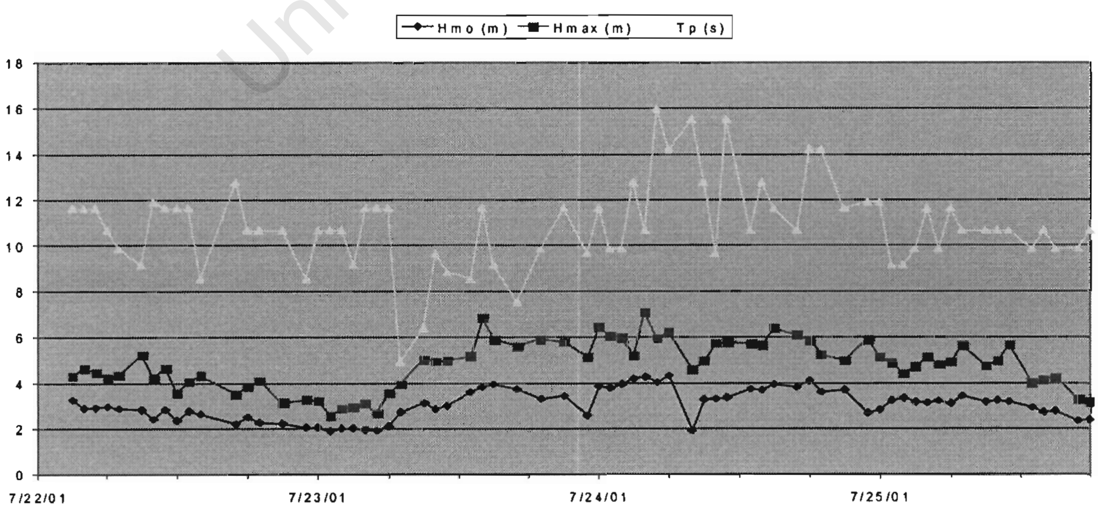
Event 13: Richards Bay



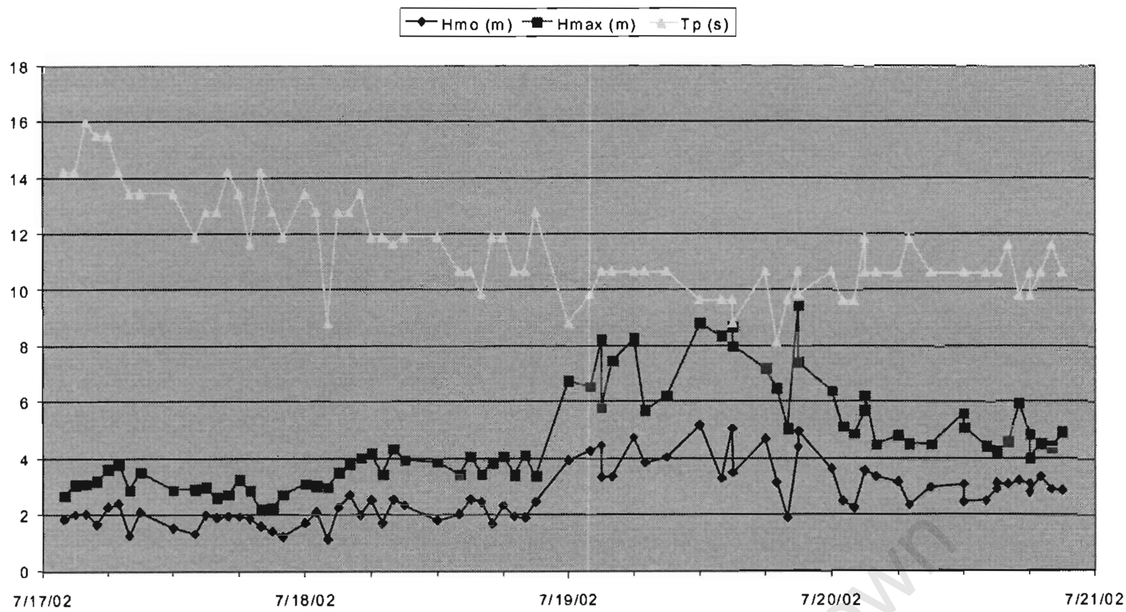
Event 14: Richards Bay



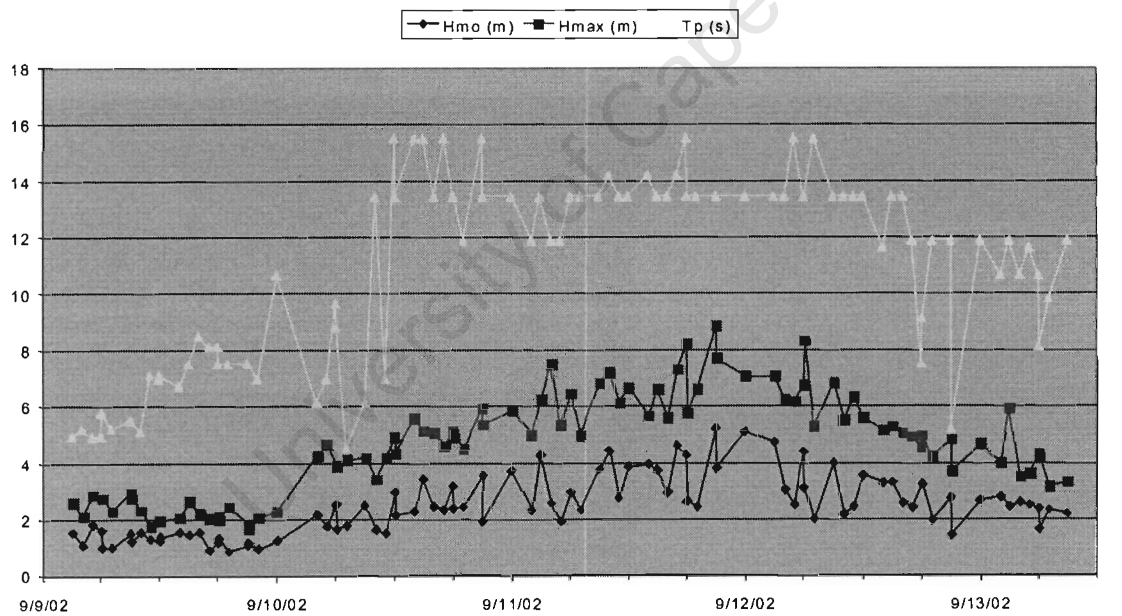
Event 15: Richards Bay



Event 16: Richards Bay

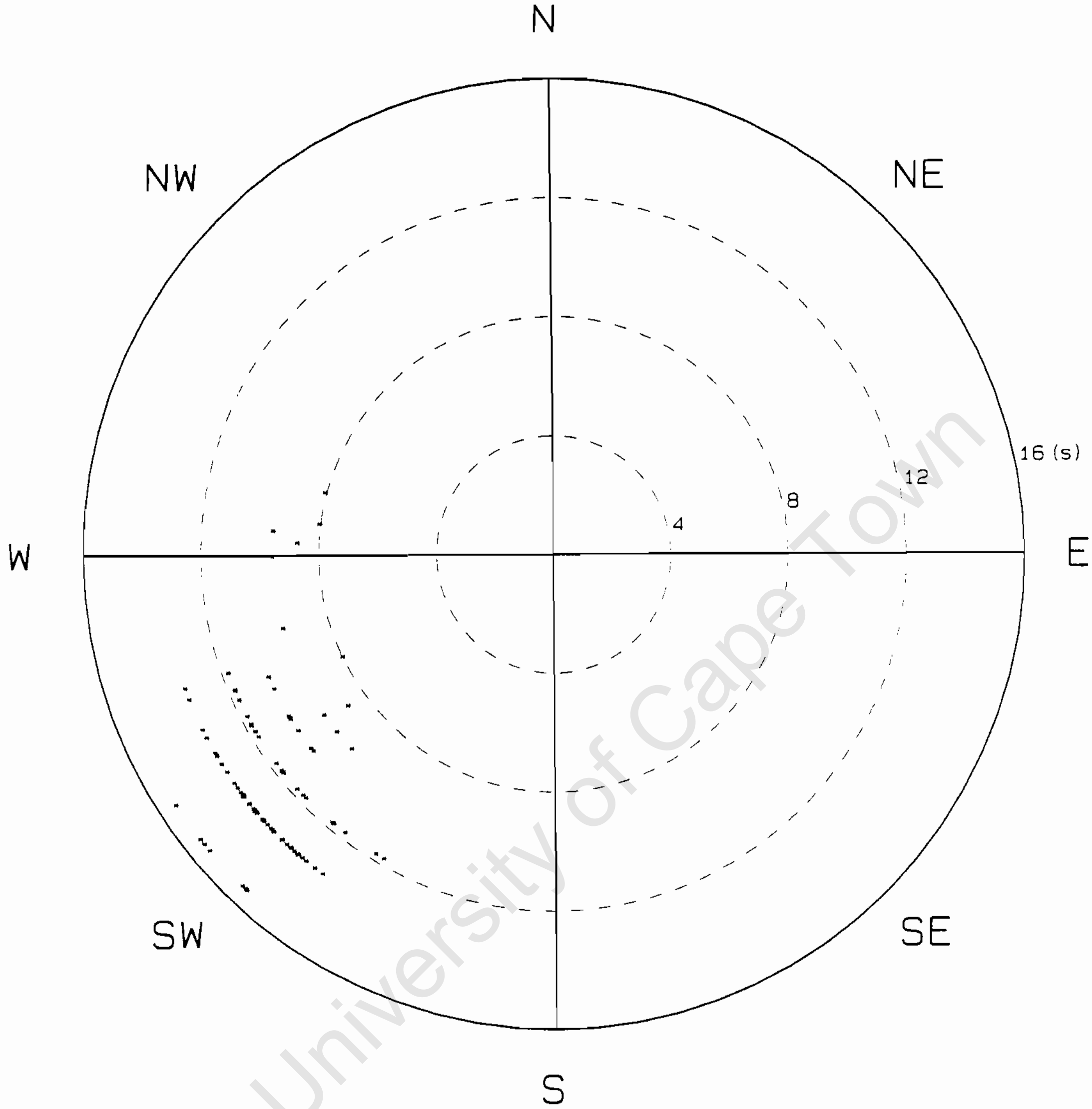


Event 17: Richards Bay



ALL DATA

No. of Records = 85



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date ....:	2000/07/13
Data End Date ......:	2000/07/16
Water Depth ....:	70 m
Instrument Type ....:	All Instruments

C S I R

Slangkop

PERIOD (TP) VERSUS DIRECTION

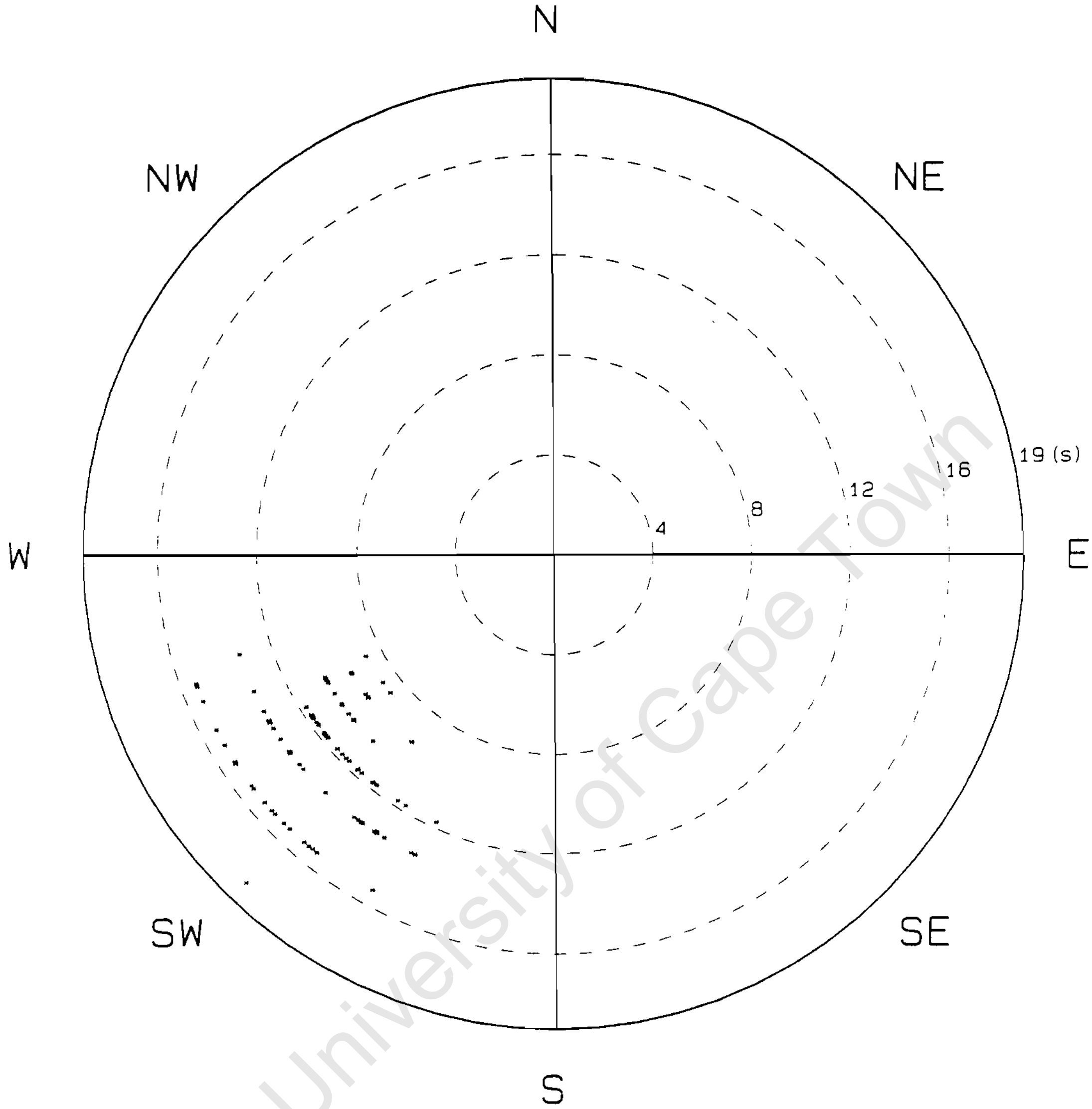
Event 25

FIGURE A

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:30:14

ALL DATA

No. of Records = 97



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date .....:	2000/07/13
Data End Date ....:	2000/07/21
Water Depth ....:	70 m
Instrument Type .....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

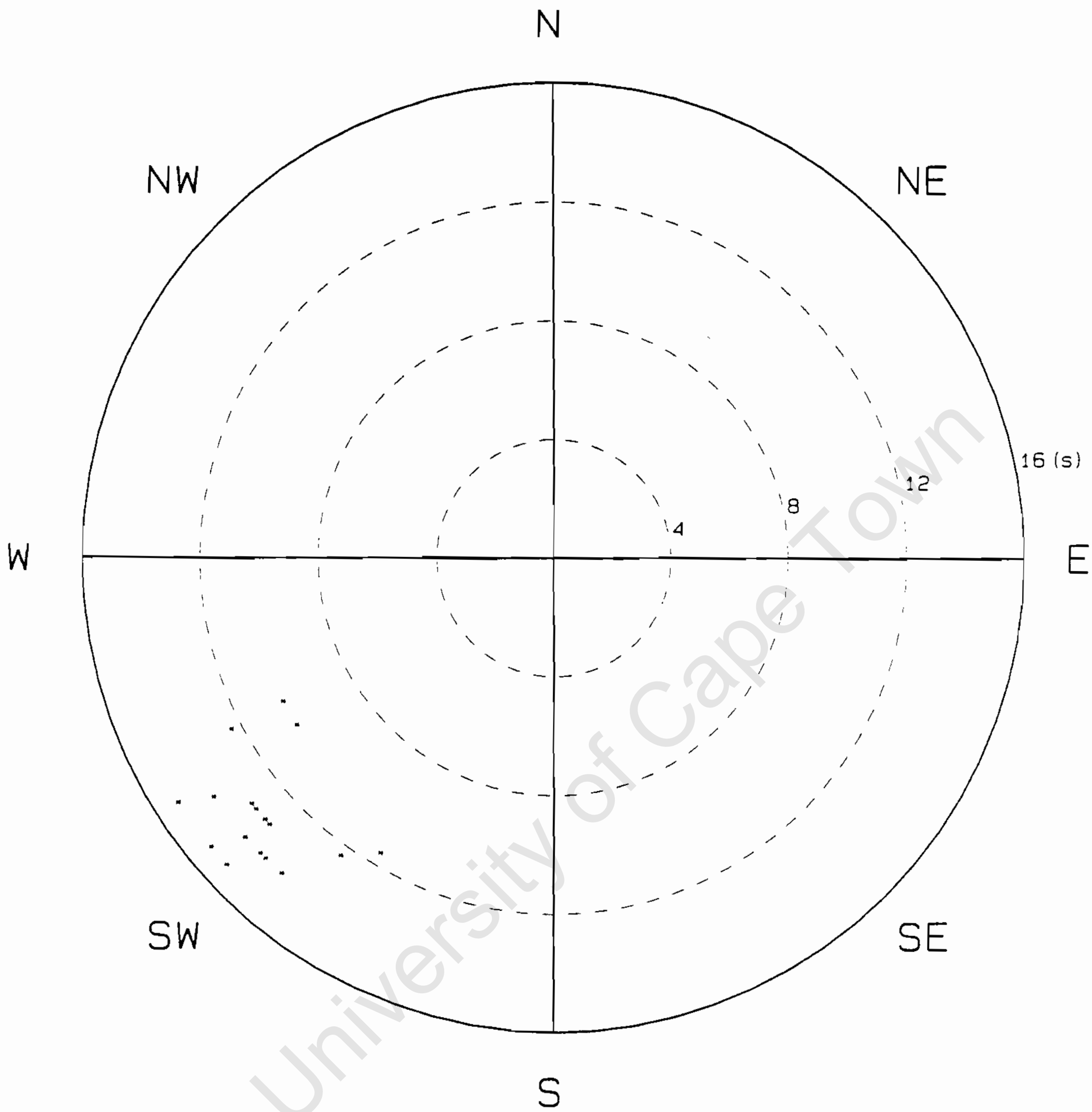
Event 26

FIGURE B

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:30:49

ALL DATA

No. of Records = 20



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date ....:	2000/07/13
Data End Date ......:	2001/08/21
Water Depth ....:	70 m
Instrument Type ....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

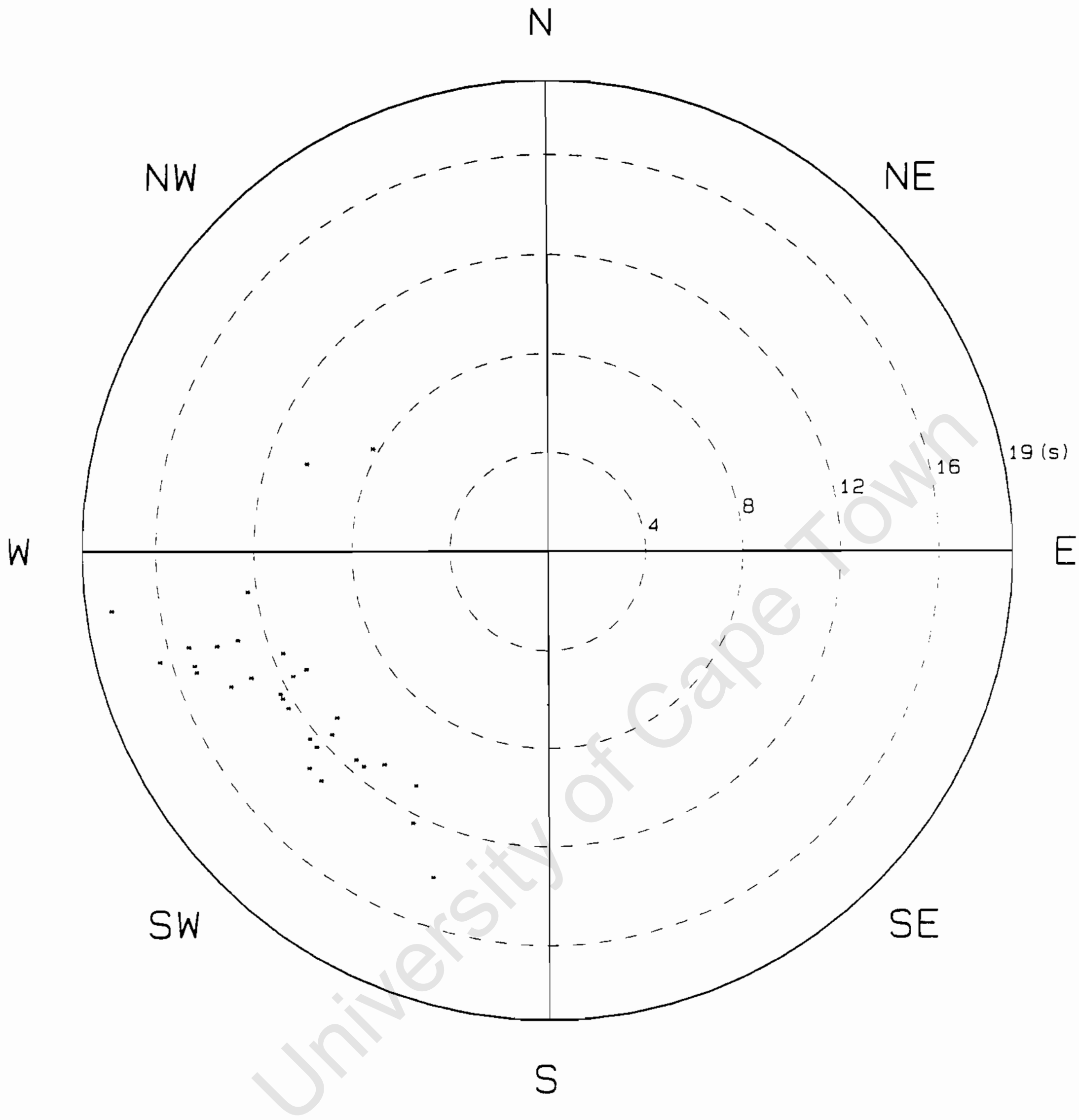
Event 27

FIGURE C

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:31:22

ALL DATA

No. of Records = 31



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date .....:	2000/07/13
Data End Date ....:	2001/09/07
Water Depth ....:	70 m
Instrument Type .....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

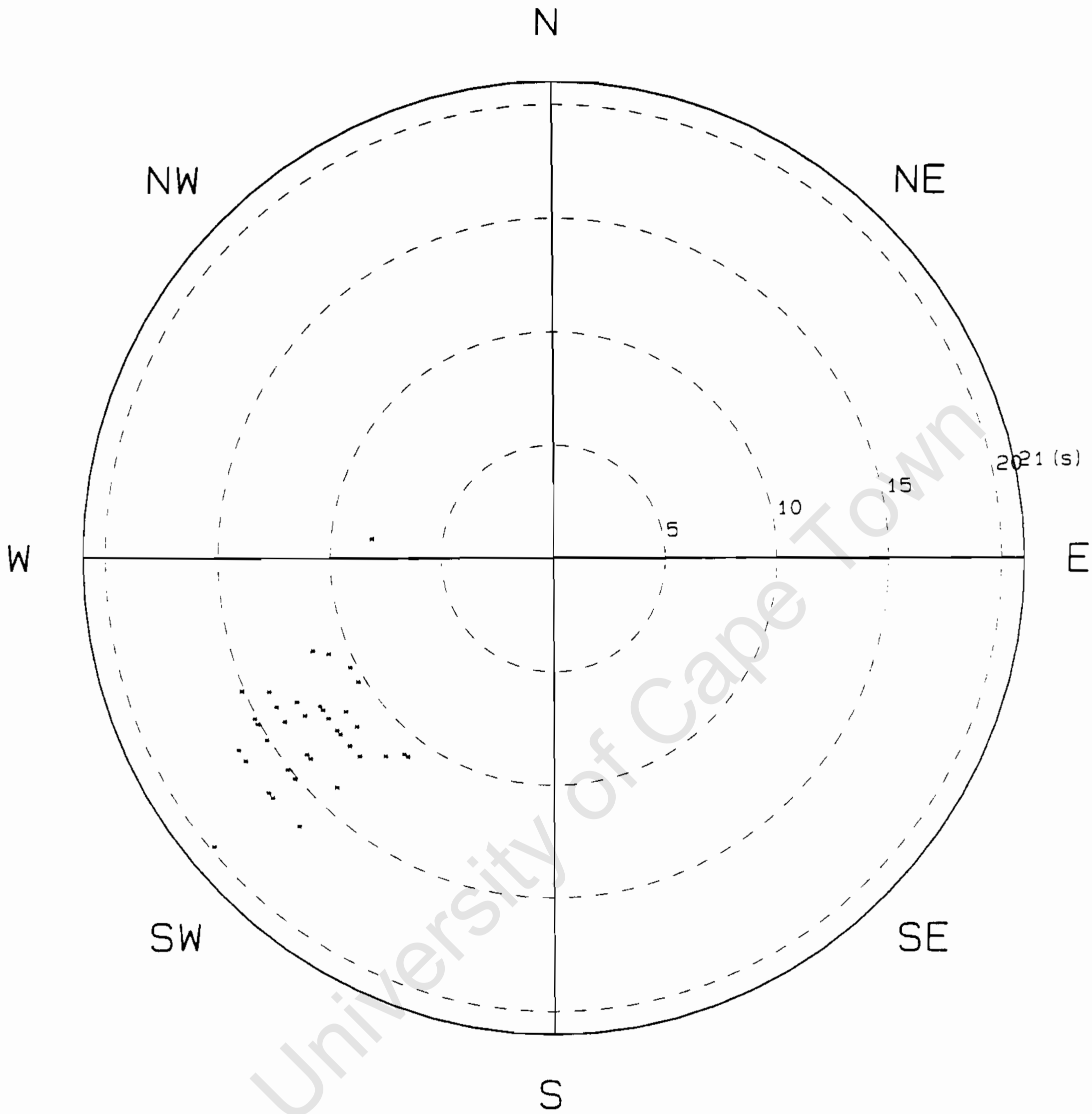
Event 28

FIGURE D

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:31:41

ALL DATA

No. of Records = 38



Station Code	........:	CP01 - CAPE POINT
Latitude	..........:	34 12.2 S
Longitude	..........:	18 17.2 E
Data Start Date	....:	2000/07/13
Data End Date	......:	2002/05/26
Water Depth	.........:	70 m
Instrument Type	....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

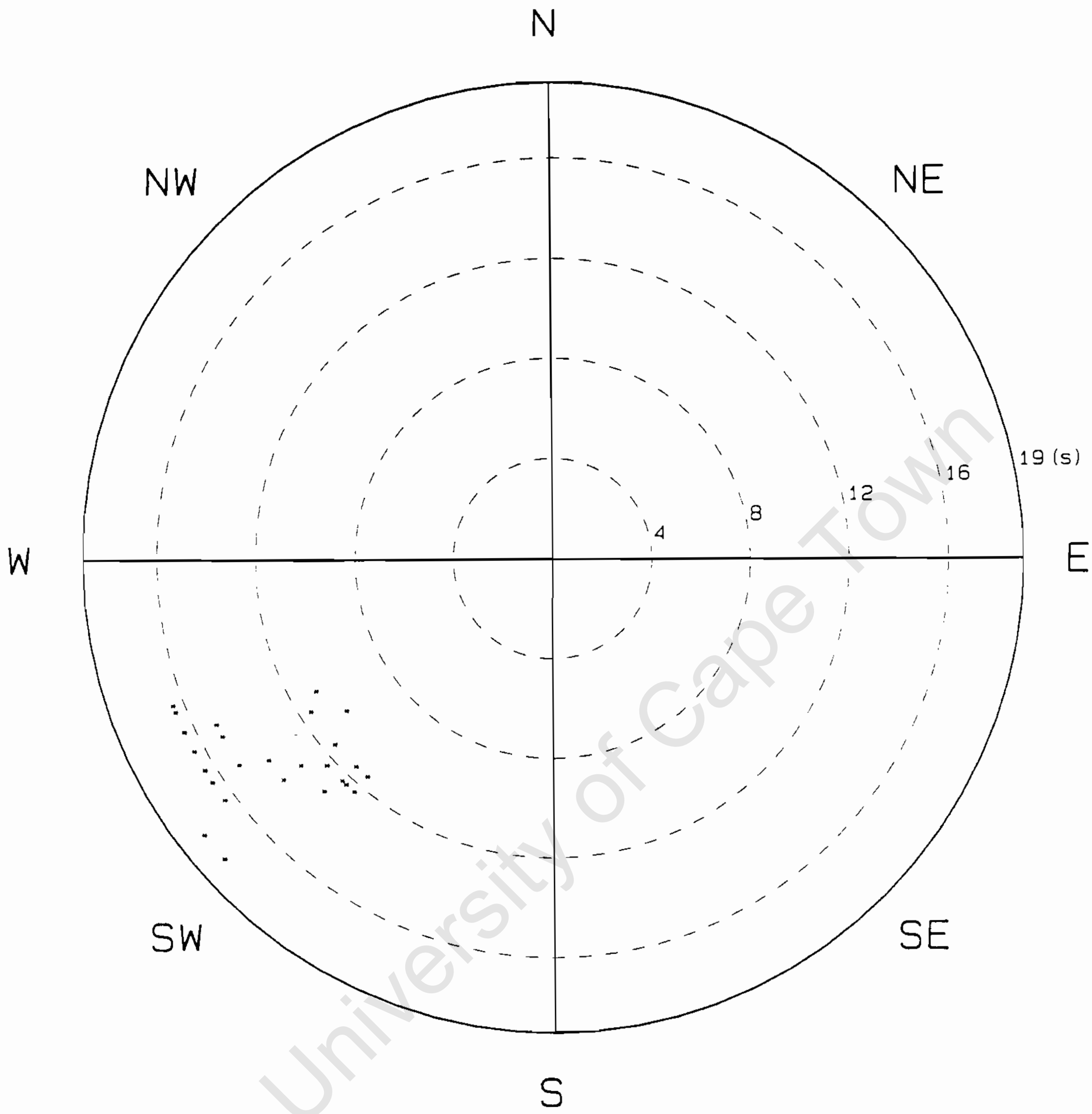
Event 29

FIGURE E

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:32:02

ALL DATA

No. of Records = 31



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date ....:	2000/07/13
Data End Date ......:	2002/06/20
Water Depth ....:	70 m
Instrument Type ....:	All Instruments

C S I R

Slangkop

PERIOD (TP) VERSUS DIRECTION

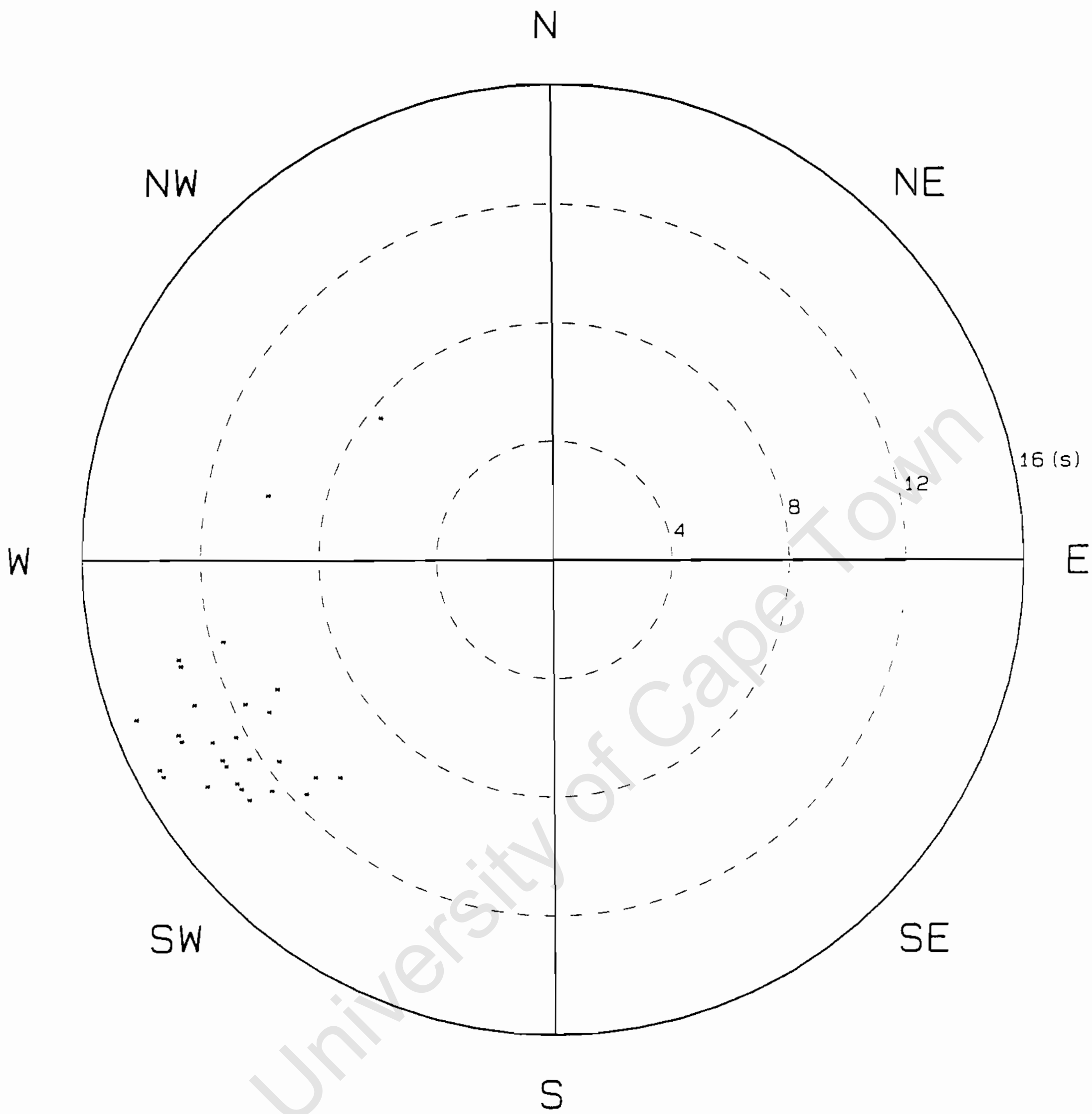
Event 30

FIGURE F

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:32:23

ALL DATA

No. of Records = 32



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date .....:	2000/07/13
Data End Date ....:	2002/07/30
Water Depth ....:	70 m
Instrument Type .....:	All Instruments

C S I R

Slangkop

PERIOD (TP) VERSUS DIRECTION

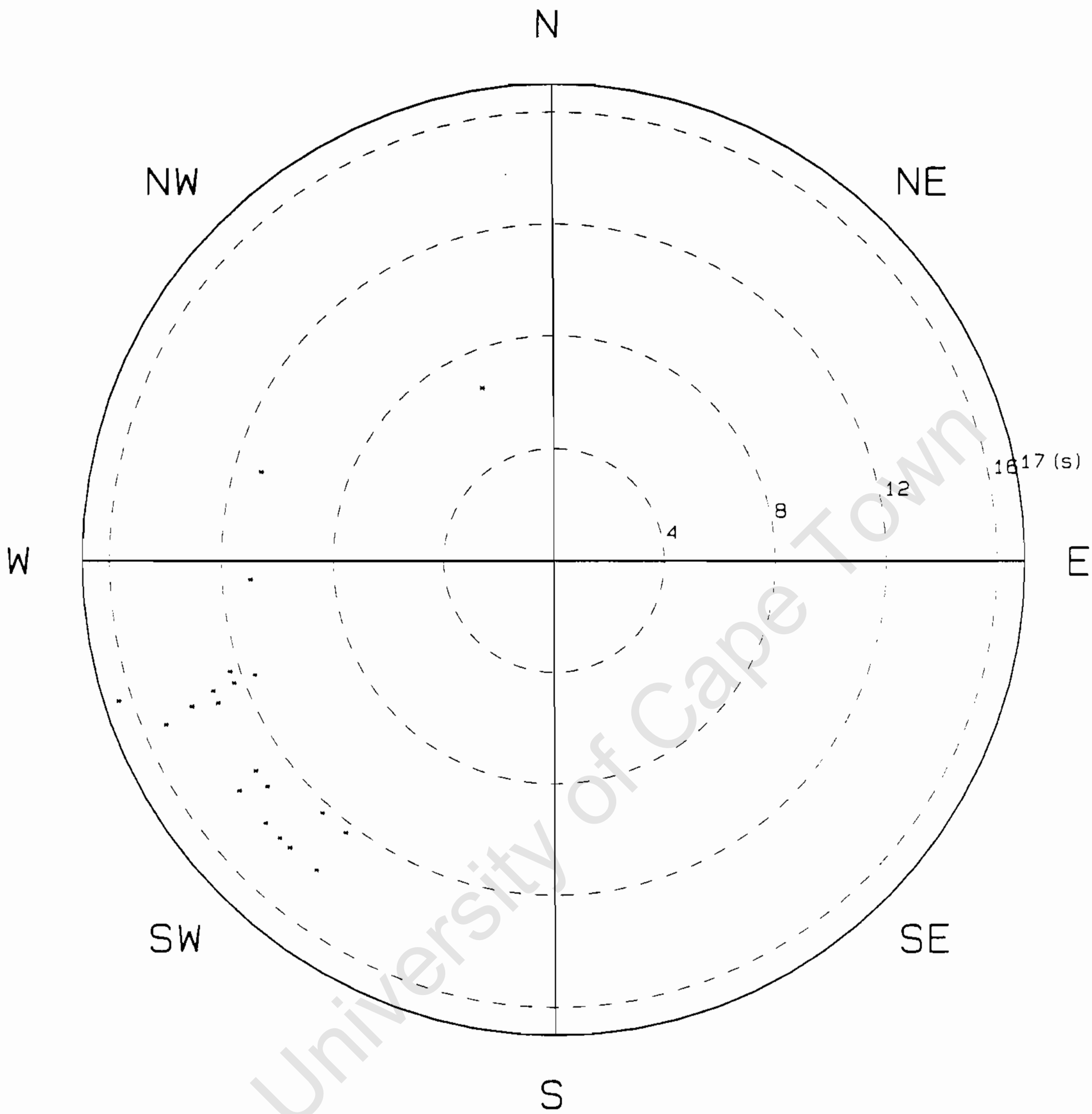
Event 31

FIGURE G

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:32:51

ALL DATA

No. of Records = 20



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date .....:	2000/07/13
Data End Date ....:	2002/08/04
Water Depth ....:	70 m
Instrument Type .....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

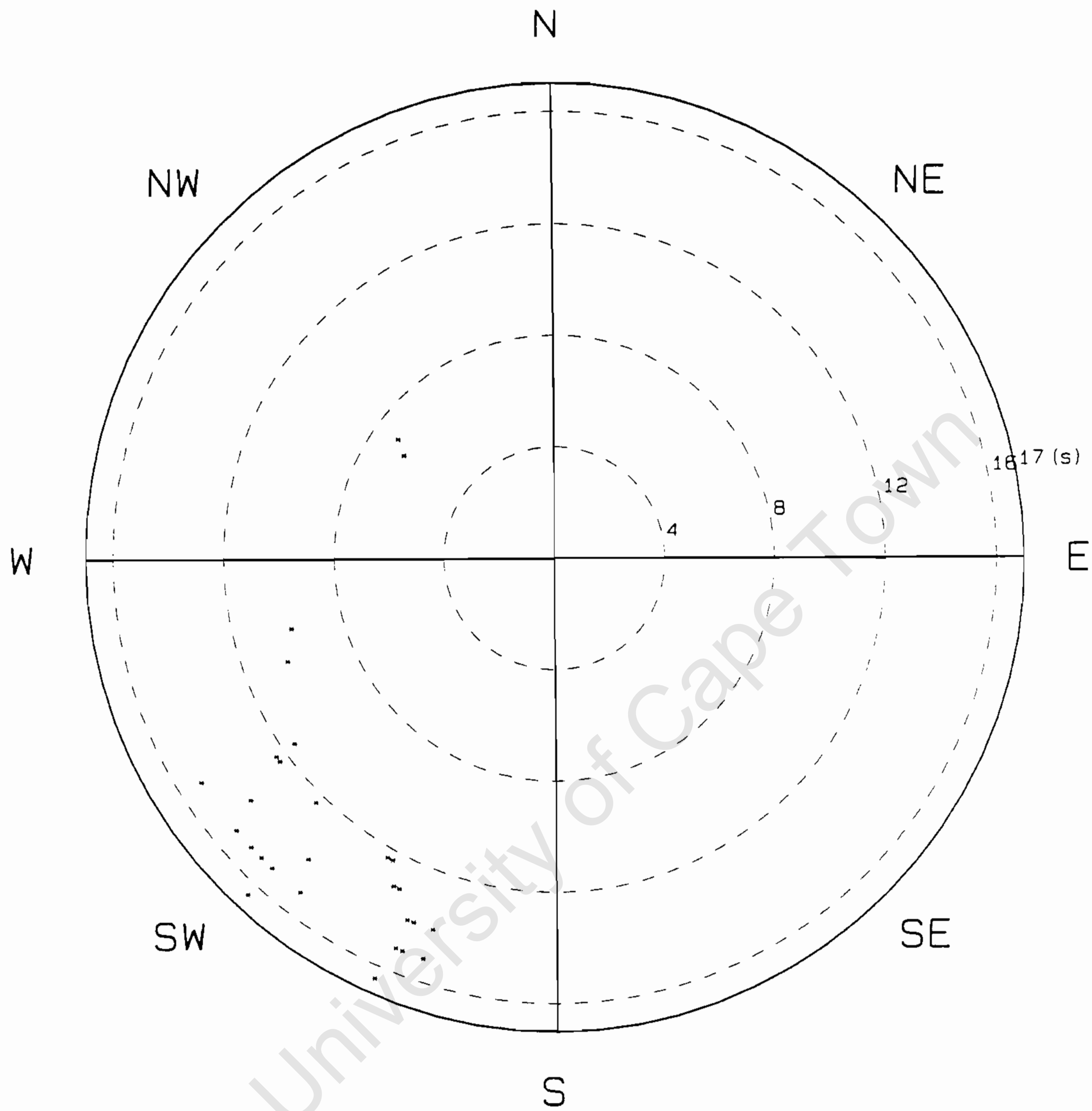
Event 32

FIGURE H

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:33:10

ALL DATA

No. of Records = 30



Station Code ....:	CP01 - CAPE POINT
Latitude ....:	34 12.2 S
Longitude ....:	18 17.2 E
Data Start Date	2000/07/13
Data End Date ......:	2003/08/21
Water Depth ....:	70 m
Instrument Type ....:	All Instruments

CSIR

Slangkop

PERIOD (TP) VERSUS DIRECTION

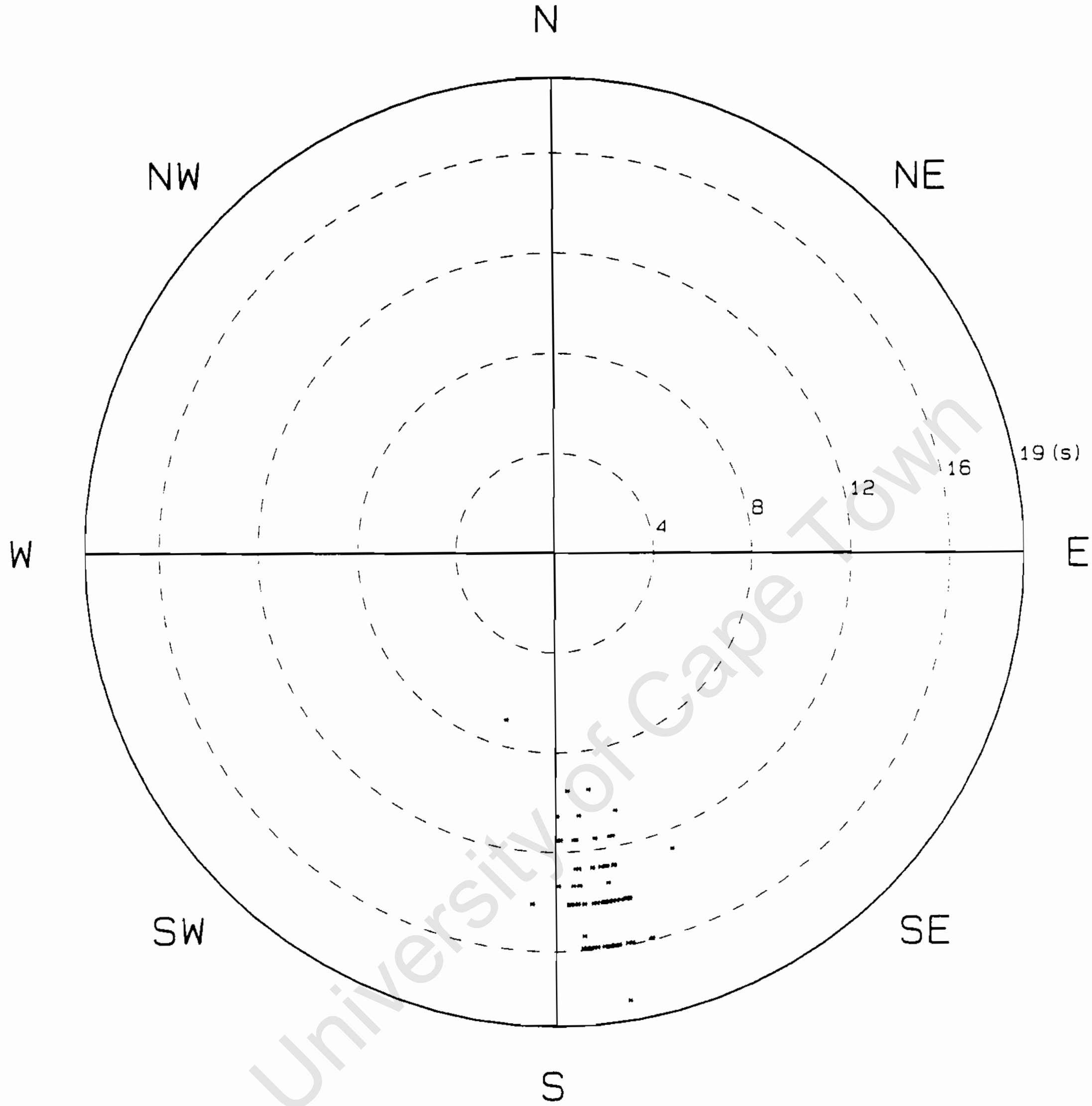
Event 33

FIGURE I

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 09:33:35

ALL DATA

No. of Records = 71



Station Code ....:	OL01
Latitude ....:	29 59.2 S
Longitude ....:	30 59.9 E
Data Start Date .....:	2001/03/11
Data End Date ....:	2001/03/14
Water Depth ....:	42 m
Instrument Type .....:	All Instrument Types

CSIR

East London

PERIOD (TP) VERSUS DIRECTION

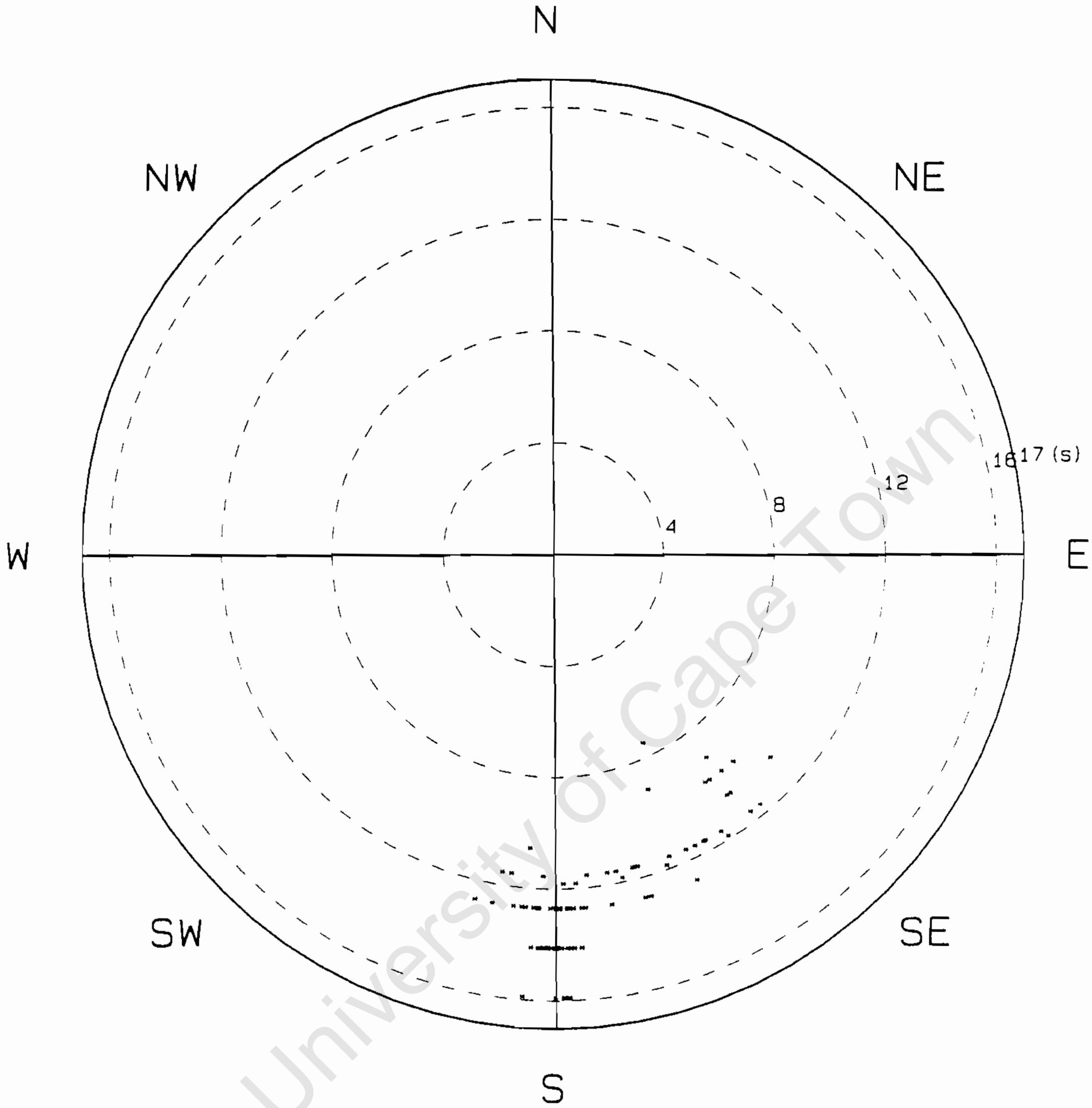
Event 14

FIGURE J

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 10:56:19

ALL DATA

No. of Records = 83



Station Code ....:	OL01
Latitude ....:	29 59.2 S
Longitude ....:	30 59.9 E
Data Start Date ....:	2001/03/11
Data End Date ......:	2002/07/19
Water Depth ....:	42 m
Instrument Type ....:	All Instrument Types

CSIR

East London

PERIOD (TP) VERSUS DIRECTION

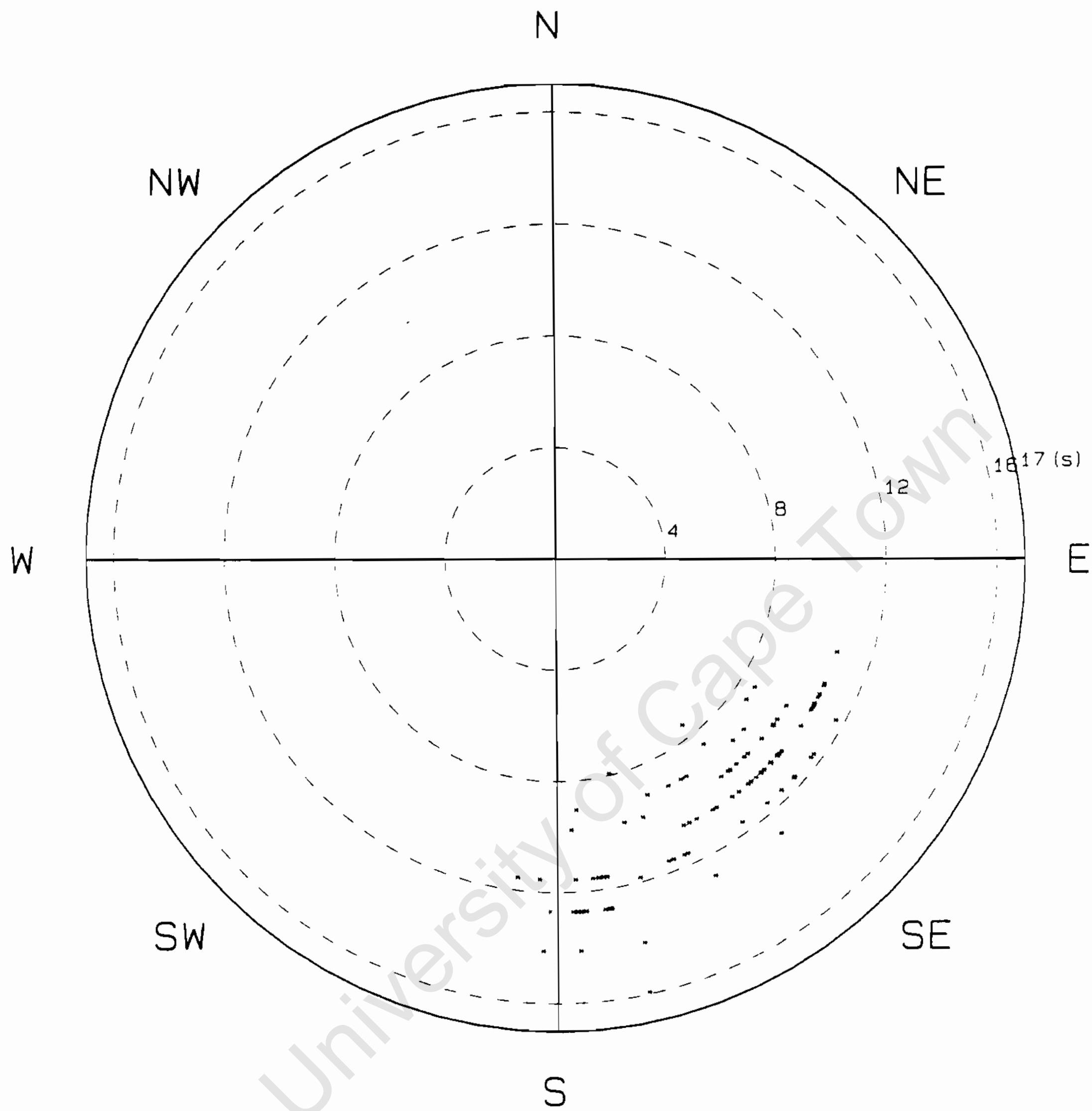
Event 15

FIGURE K

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 10:56:41

ALL DATA

No. of Records = 92



Station Code ....:	OL01
Latitude ....:	29 59.2 S
Longitude ....:	30 59.9 E
Data Start Date ....:	2001/03/11
Data End Date	2002/08/17
Water Depth ....:	42 m
Instrument Type ....:	All Instrument Types

CSIR

East London

PERIOD (TP) VERSUS DIRECTION

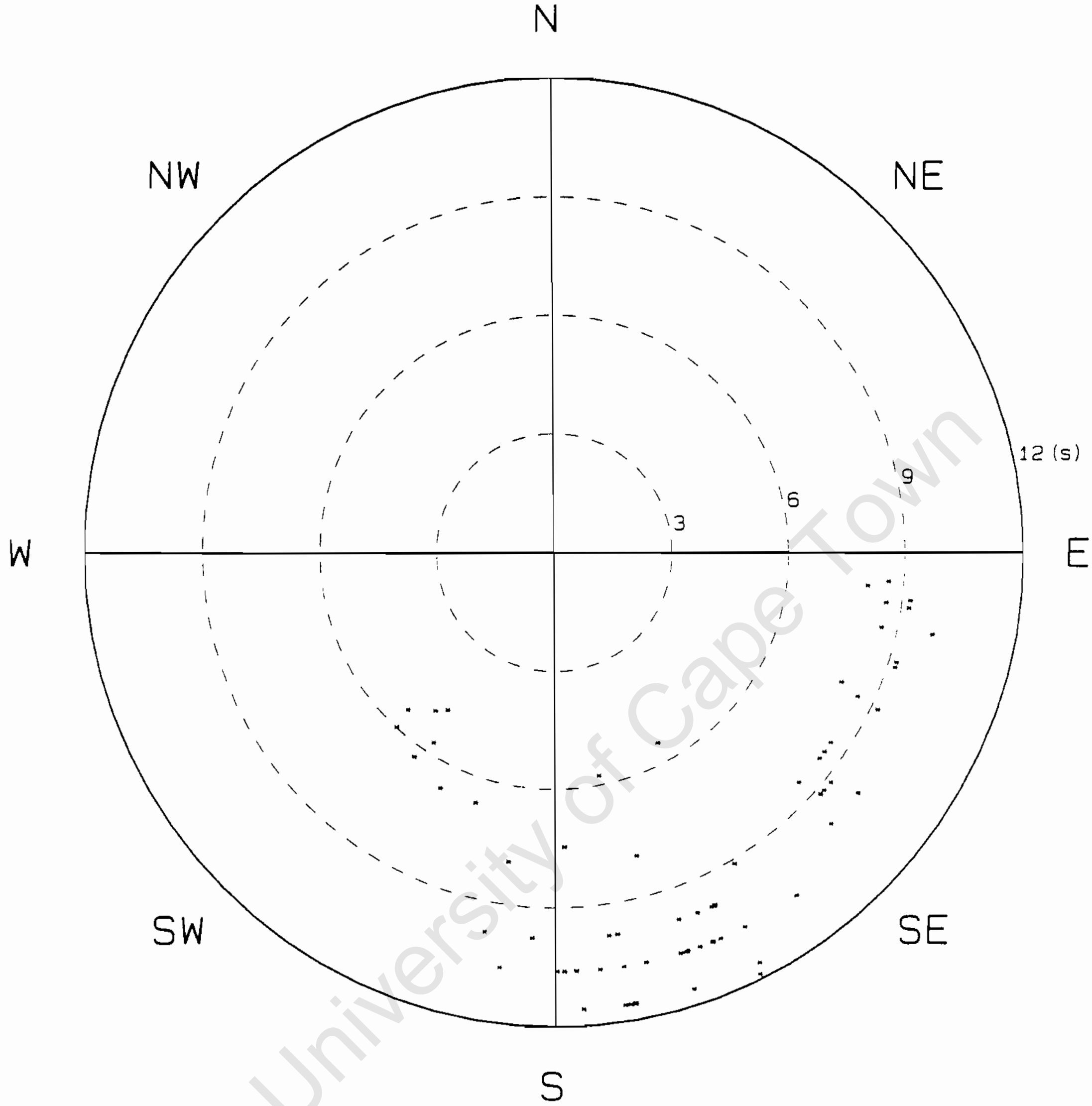
Event 16

FIGURE L

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 10:57:11

ALL DATA

No. of Records = 68



Station Code ....:	OL01
Latitude ....:	29 59.2 S
Longitude ....:	30 59.9 E
Data Start Date .....:	2001/03/11
Data End Date ....:	2002/09/11
Water Depth ....:	42 m
Instrument Type .....:	All Instrument Types

C S I R

East London

PERIOD (TP) VERSUS DIRECTION

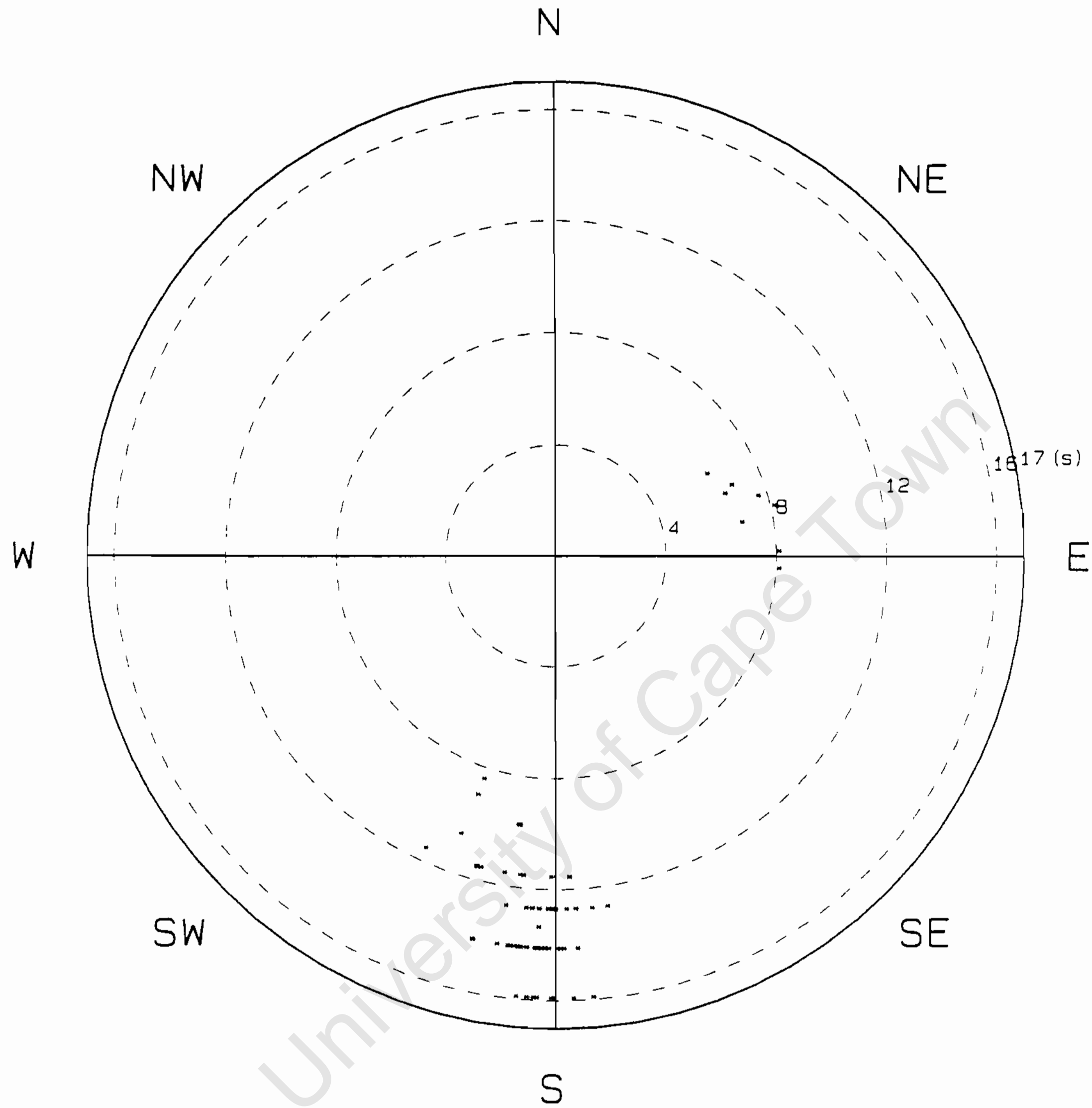
Event 17

FIGURE M

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 10:57:27

ALL DATA

No. of Records = 64



Station Code ....:	OL01
Latitude ....:	29 59.2 S
Longitude ....:	30 59.9 E
Data Start Date ....:	2001/03/11
Data End Date ......:	2002/10/04
Water Depth ....:	42 m
Instrument Type ....:	All Instrument Types

CSIR

East London

PERIOD (TP) VERSUS DIRECTION

Event 19

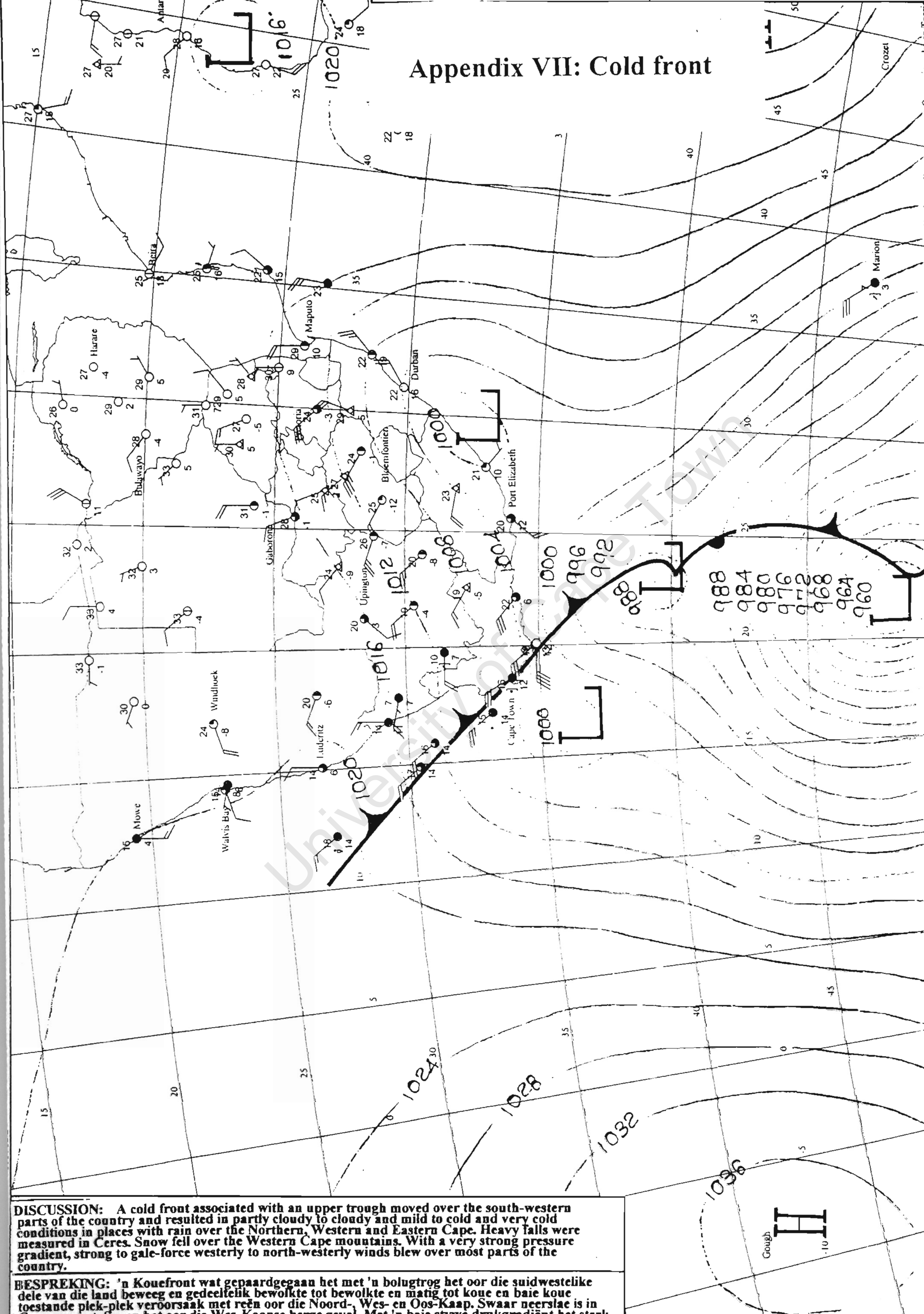
FIGURE 0

Wav_Dir/SCAT (LW Coetzee/U v St Ange) 2004/02/13 10:57:49

SYNOPTIC WEATHER MAP
SINOPTIESE WEERKAART

12:00 UT - 14:00 SAST:2003-08-18

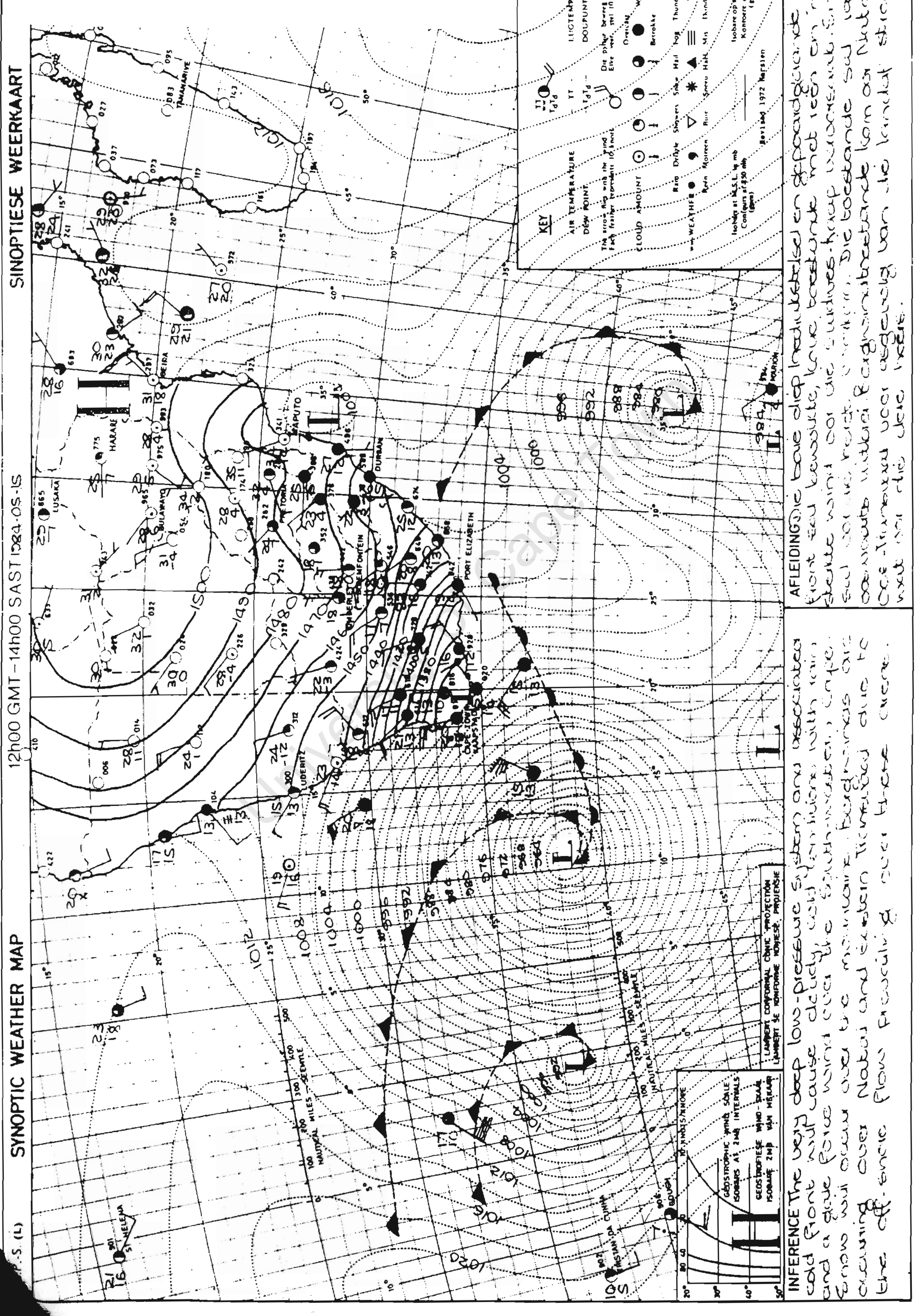
Appendix VII: Cold front



DISCUSSION: A cold front associated with an upper trough moved over the south-western parts of the country and resulted in partly cloudy to cloudy and mild to cold and very cold conditions in places with rain over the Northern, Western and Eastern Cape. Heavy falls were measured in Ceres. Snow fell over the Western Cape mountains. With a very strong pressure gradient, strong to gale-force westerly to north-westerly winds blew over most parts of the country.

BESPREKING: 'n Kouefront wat gepaardgegaan het met 'n bolugtrog het oor die suidwestelike dele van die land beweeg en gedeeltelik bewolkte tot bewolkte en matig tot koue en baie koue toestande plek-plek veroorsaak met reën oor die Noord-, Wes- en Oos-Kaap. Swaar neerslae is in Ceres gemeet. Sneeu het oor die Wes-Kaapse berge geval. Met 'n baie stywe drukgradiënt het sterk tot stormsterk weste- tot noordwestewinde oor die grootste gedeelte van die land gewaai.

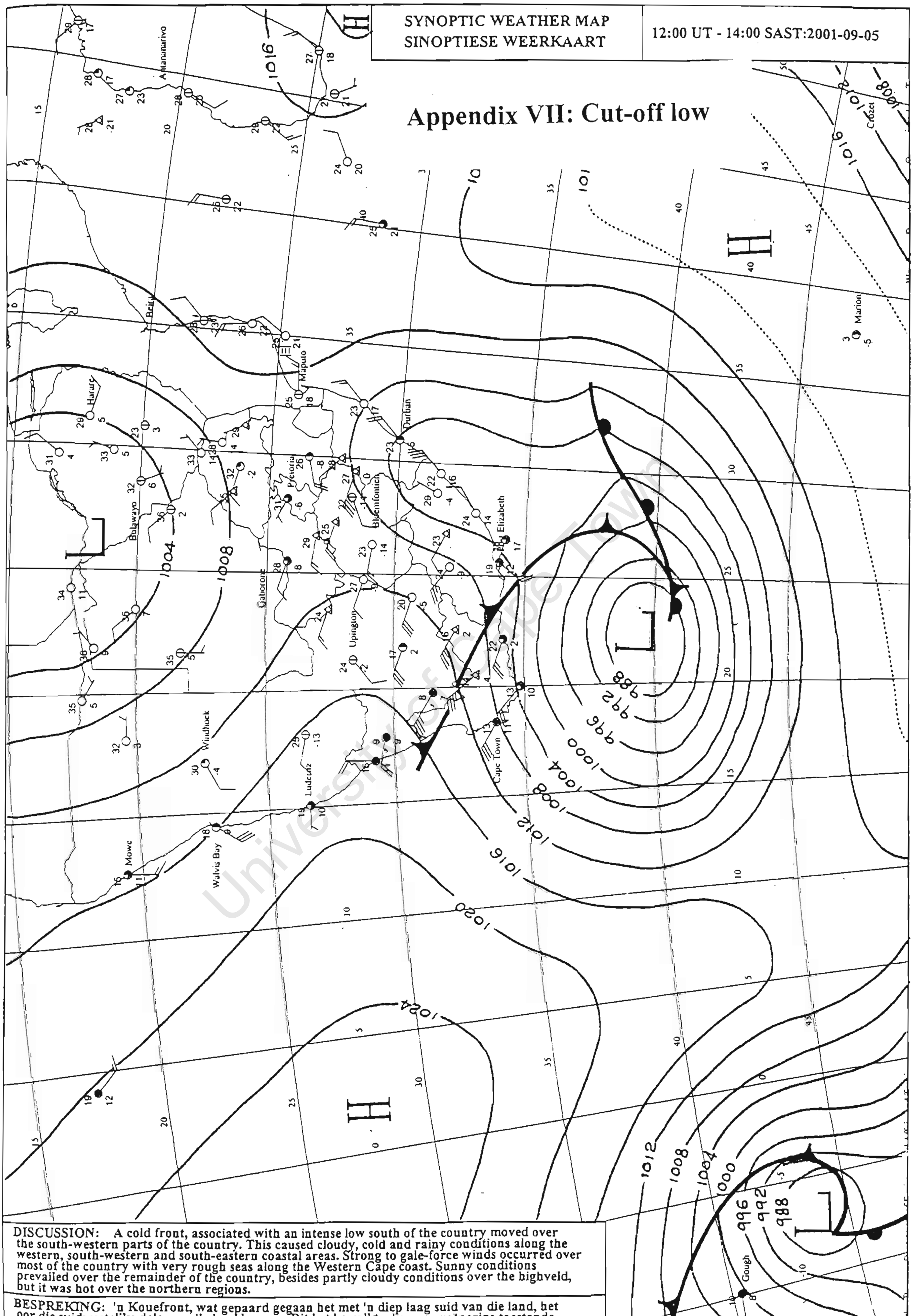
Appendix VII: Explosive cyclogenesis



SYNOPTIC WEATHER MAP
SINOPTIESE WEERKAART

12:00 UT - 14:00 SAST:2001-09-05

Appendix VII: Cut-off low

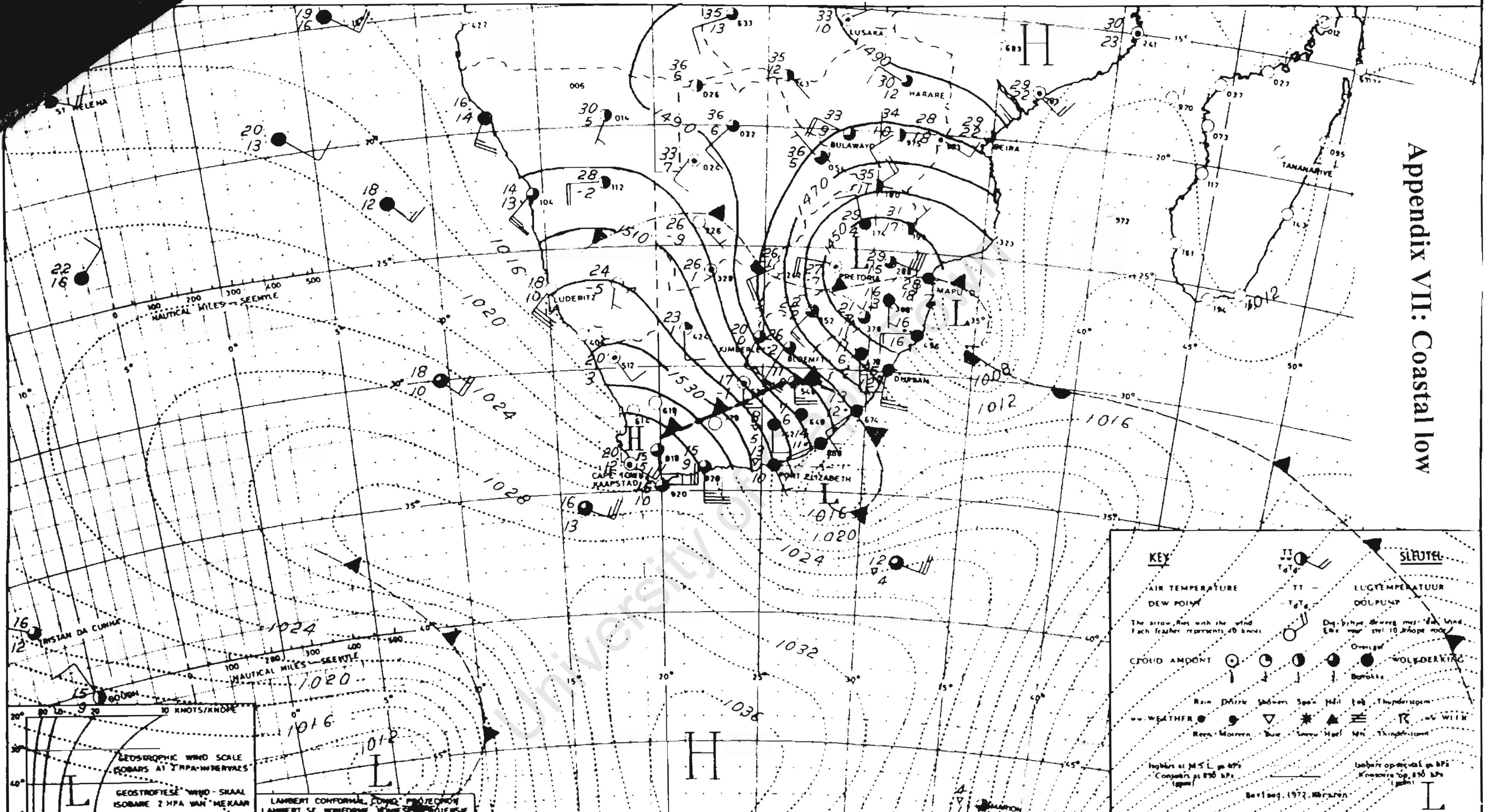


DISCUSSION: A cold front, associated with an intense low south of the country moved over the south-western parts of the country. This caused cloudy, cold and rainy conditions along the western, south-western and south-eastern coastal areas. Strong to gale-force winds occurred over most of the country with very rough seas along the Western Cape coast. Sunny conditions prevailed over the remainder of the country, besides partly cloudy conditions over the highveld, but it was hot over the northern regions.

BESPREKING: 'n Kouefront, wat gepaard gegaan het met 'n diep laag suid van die land, het oor die suidwestelike dele van die land beweeg. Dit het bewolkte, koue en reënerige toestande langs die westelike, suidwestelike en suidoostelike kusgebiede veroorsaak. Sterk tot stormsterk winde het oor die grootste dele van die land voorgekom, met ruwe see langs die Wes-Kaapse kus. Sonnige toestande het oor die res van die land geheers, behalwe gedeeltelik bewolkte toestande oor die hoëveld, maar dit was baie warm oor die noordelike streke.

Appendix VII: Coastal low

OPTIC WEATHER MAP | 12:00 UT – 14:00 SAST *1990-10-18* | SINOPTIESE WEERKAART | MET 1/2/6

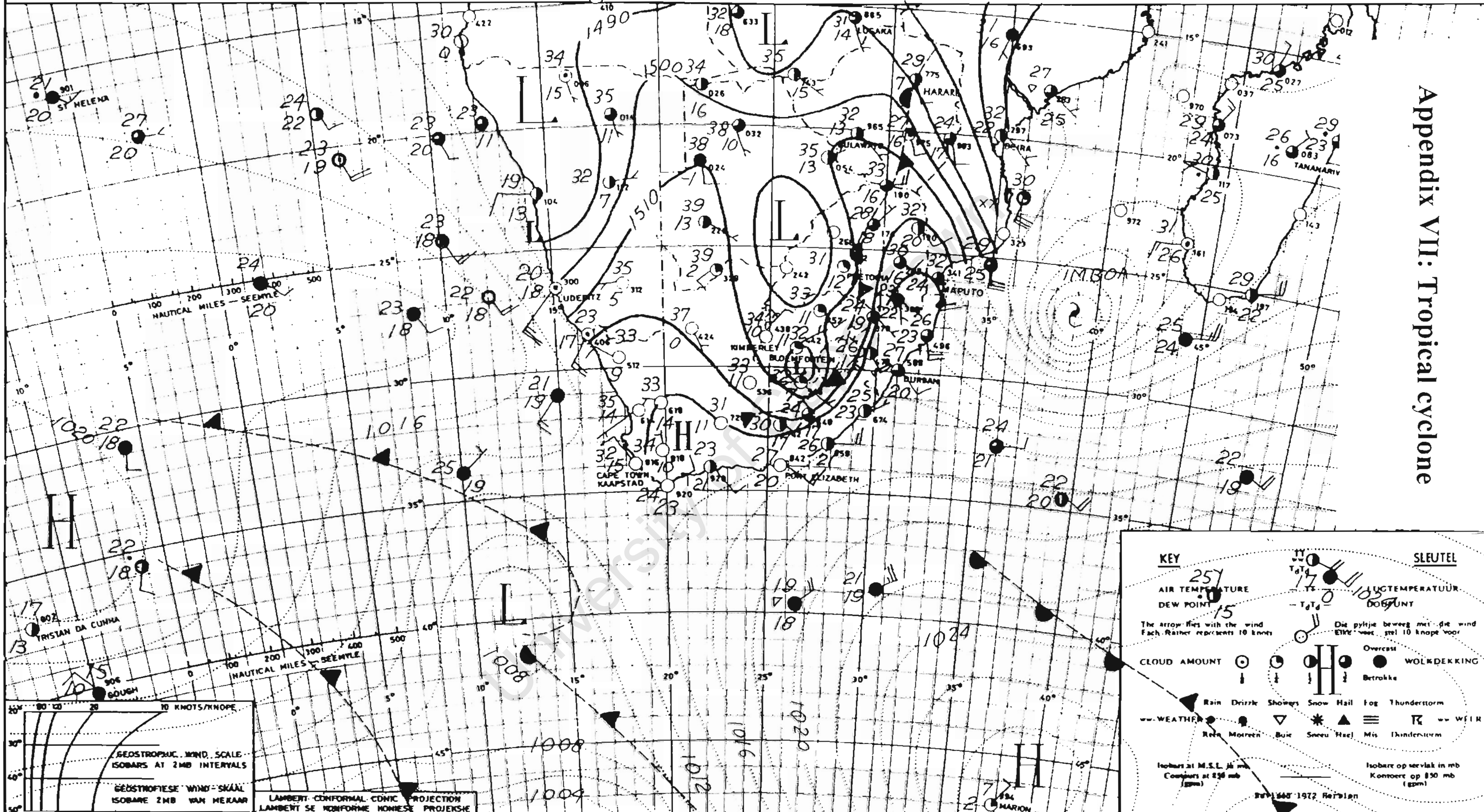


INFERENCE Cloudy and cold to bitterly cold conditions with scattered showers, and snow showers over the berg areas, are prevailling over the southern parts of the country. Only isolated showers are occuring over Eastern Transvaal and Eastern Free State.

AFLEIDING Bewolkte en koue tot uiters koue toestande met verspreide buie, en sneeubuie oor die bergdele, heers oor die suidelike dele van die land. Slegs enkele buie kom oor Oos-Transvaal en Oos-Vrystaat voor.

Appendix VII: Tropical cyclone

G.P.-S. (L) **SYNOPTIC WEATHER MAP** 12h00 GMT - 14h00 SAST 1984.02.16 **SINOPTIESE WEERKAART** TV 4/42



INFERENCE Tropical cyclone Imboa is weakening and moving very slowly. An inshore flow over the eastern areas of the country will cause cloudy weather over these areas with light rain in places. Isolated thundershowers will develope over the central interior.

AFLEIDING Tropie sikloon Imboa verswak en beweeg baie stadig. ń Landwaartse stroming oor die oostelike dele van die land sal bewolkte toestande oor hierdie dele veroor saak met ligte reen op plekke. Enkele donderbuie sal oor die sentrale binneland ontwikkel.